MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

VOL. 66, No. 9
W. B. No. 1248

SEPTEMBER 1938

CLOSED NOVEMBER 3, 1938
ISSUED DECEMBER 28, 1938

ON THE USE OF VERTICAL CROSS SECTIONS IN STUDYING ISENTROPIC FLOW

By CHARLES H. PIERCE

[Weather Bureau, Washington, D. C., October 1938]

The isentropic chart is proving more and more valuable to the synoptic meteorologist, but it has one disadvantage—it shows only a very thin sheet of the free atmosphere. Often the meteorologist wants a more complete picture of the upper air than given by the one or two isentropic charts that he may have at hand. This is especially true in the vicinity of frontal activity. To thus aid the meteorologist, and to serve as a helpful link between the isentropic chart and the surface map, vertical cross sections showing the arrangement of the various isentropic surfaces from the ground up to 5 or more kilometers are useful.

It has been found that the quantities to be represented in order to give the best thermodynamic interpretation of the cross section are potential temperature and the isentropic condensation temperature. These are expressed in degrees A. As supplementary data to these values, temperature, specific humidity, relative humidity, equivalent potential temperature, winds, and hydrometeors may be entered to aid in the final analysis of the cross section. In the examples presented here, solid lines are drawn through equal potential temperatures, and dotted lines represent equal isentropic condensation temperatures. Isotherms of potential temperature of course represent isentropic surfaces. Isentropic condensation temperature of a mass of air is defined as the temperature it would have if it were raised adiabatically without gain or loss of water vapor to the condensation level. On any one isentropic surface this value is a direct function of specific humidity and therefore can be used to indicate the moisture distribution in the air. Proof of this is found in a paper by Byers.[1] Therefore lines of constant condensation temperature on an isentropic surface correspond to lines of constant specific humidity. However, in a cross section, several different potential temperatures occur so that θ is a variable and T_0-isotherms do not correspond to q-isograms. For a given condensation temperature the specific humidity would be different at every level or pressure.

This variation of q with p for a given condensation temperature can be shown by differentiating equation (2) of Byer's paper holding T_0 constant, which according to equation (5) means e_0 contant.[2] We find that this variation for a difference of 100 mb at levels up to 5 km is 20 percent or less. In other words, for a T_0 of 14° C. at 1,000 mb we have a specific humidity of 10.3 grams per kilogram while at 900 mb it increases to 11.4 grams, which gives a variation of 10 percent. Isentropic condensation temperature is invariant in an adiabatic process as is specific humidity. Also, there is no appreciable change in the flow pattern when isotherms of isentropic condensation temperature are used in place of isograms of specific humidity so that it seems reasonable to use it in place of specific humidity, especially after considering the advantages.

ADVANTAGES

One advantage is that a better thermodynamic interpretation can be derived from the use of the two values, potential temperature and condensation temperature. Since air cools approximately 1° C. per 100 meters of ascent in an adiabatic process, the height of the condensation level above 1,000 mb can be determined by subtracting the isentropic condensation temperature from the potential temperature at any point on the cross section and multiplying the difference by 100. Therefore, if there is a difference of 45° between potential temperature and condensation temperature for a certain particle of air on the cross section, condensation would be expected at 4,500 meters above the 1,000 mb level. If the particle in question is already located, let us say, at 4,200 meters, then it is close to condensation, but if it is at 1,200 meters then it must undergo considerable lifting along the isentropic surface before condensation takes place. The height of saturation above sea level can easily be found by adding the height above sea level of the 1,000-mb surface to the original height, which in the above case was 4,500 meters. Allowing, as a rough average, 100 meters for every 12 mb between the sea-level pressure and 1,000 mb, the height at which the pressure of 1,000 mb is located can roughly be estimated from the surface map. A slight error is introduced by assuming that the same pressure gradient exists at intermediate and high levels that is found at the earth's surface. However, this assumption is negligible during both winter and summer, amounting to not more than 200 or 300 meters.

An example of how the isentropic condensation temperature can thus be used is found in the cross section of January 11, 1938, from Omaha to Chicago (fig. 1). At 900 meters at Omaha a potential temperature of 287° and a condensation temperature of 265° are found. Subtracting one from the other we have a difference of 22° which means condensation might be expected at 2,200 meters above the 1,000 mb level. Because the air flow was directed toward Chicago, the sea-level pressure for that station, which was 1,011 mb, is taken. This places the 1,000 mb level at 100 meters above sea level. Adding this to 2,200 meters, we find that the condensation level for this element of air in the vicinity of Chicago is 2,300 meters above sea level. It is noted that the 285° isentropic surface slopes sharply to 2,600 meters at Chicago, therefore it would be expected that condensation would take place slightly west of Chicago if the particles having the same properties as those at Omaha were flowing up the slope. This is borne out by the fact that we find clouds on the 287° surface at Chicago.

[1] Byers, H. R. On the Thermodynamic Interpretation of Isentropic Charts, Mo. Wea. Rev., Vol. 66, pp. 63-68, March 1938.
[2] Ibid. fn. 1.

In the illustrations the symbolism used is the following: The thin solid lines represent isotherms of potential temperature drawn for every 5° C. The thin broken lines represent isotherms of isentropic condensation tempera-

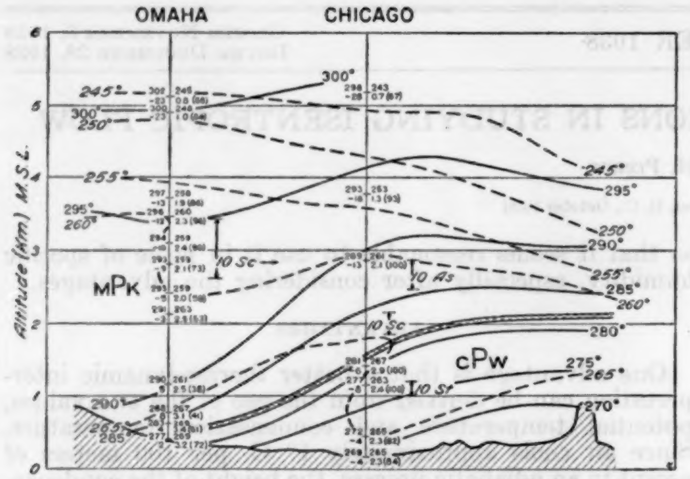


FIGURE 1.—Cross section, Omaha-Chicago, January 11, 1938.

ture drawn for every 5° C. The cross hatched lines represent warm fronts. The heavy solid lines represent cold fronts. The cross-hatched broken lines represent inactive fronts or surfaces of subsidence.

The four elements of the station data are arranged with the potential temperature at the upper left; isentropic condensation temperature at the upper right; temperature at the lower left; and specific humidity (Relative humidity) at the lower right.

The air mass symbols used are those of the thermodynamic air mass classification introduced by Bergeron. The significance of this classification is given in Willett's "American Air Mass Properties." Vol. II, No. 2, Paper in Physical Oceanography and Meteorology.

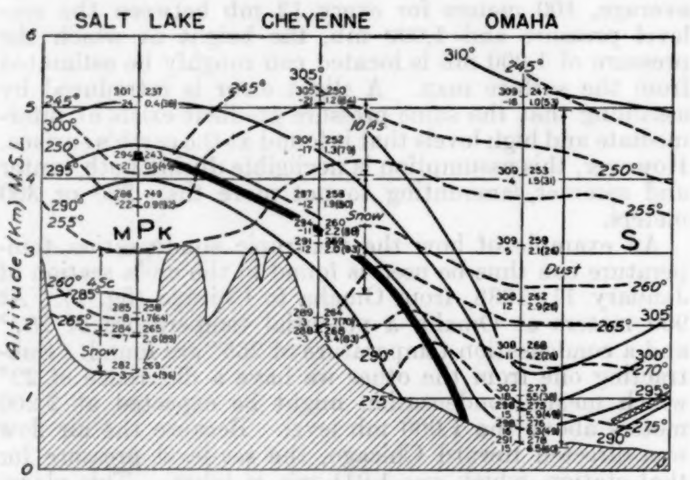


FIGURE 2.—Cross section, Salt Lake City-Omaha, March 18, 1938.

In addition to showing the source region, Bergeron's classification also gives an indication of the existing lapse rate of the air mass. The letter K (Kalt or Cold) indicates the air mass as a whole is colder than the surface over which it is traveling. In other words the lapse rate is conditionally unstable and the instability of the air column is increasing or remaining the same. The letter W (Warm) shows that the air mass is warmer than the surface over which it is traveling and is therefore stable with increasing stability. The symbols used in the illustrations are: cPw—continental Polar warm; mPk—maritime Polar cold; mPw—maritime Polar warm; mTk—maritime Tropical cold; mTw—maritime Tropical warm; S—Superior.

Of course the use of isotherms of isentropic condensation temperatures means that the condensation level must be found indirectly from the cross section. There are those, such as airway forecasters, who are not as interested in the flow pattern as they are in being able

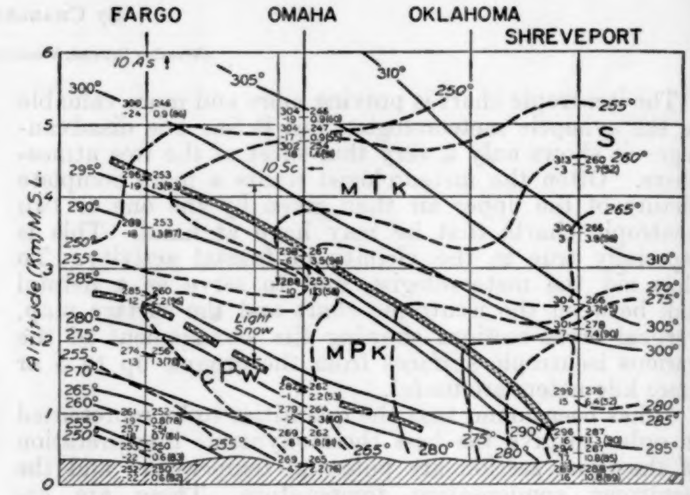


FIGURE 3.—Cross section, Fargo-Shreveport, February 15, 1938.

to tell directly upon examining the cross section what the condensation level is of any air parcel. If such is the case, then iso-lines showing the height of the condensation level may be drawn to replace isotherms of condensation temperature.

The easiest and quickest method of finding the condensation level is by subtracting the dew-point from the actual temperature for each significant level; this difference is multiplied by 100 because air cools approximately 1° C. per 100 meters. The product is added to the original height to give the height in meters above sea-level of the condensation level for direct vertical convection. The error is not appreciable if this condensation level is also used for advective motion along the isentropic surface. Iso-lines are then drawn through points having

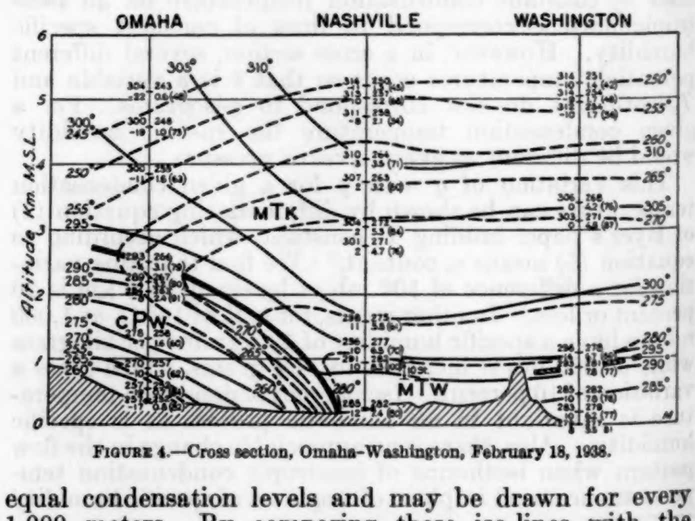


FIGURE 4.—Cross section, Omaha-Washington, February 18, 1938.

equal condensation levels and may be drawn for every 1,000 meters. By comparing these iso-lines with the actual height on the cross section, the nearness to saturation of the air can be seen at a glance.

An advantage of the T_0-isotherms over isograms of specific humidity is that they give a more representative difference in moisture content in cold air and also there is no crowding of lines in the high moisture content of the tropical maritime air.

It will be noted then that the isentropic cross sections are constructed entirely of isotherms.

VALUE OF CROSS SECTIONS

The isentropic chart usually shows the approximate flow pattern for other surfaces not too far above and below it. During the winter, however, measurable precipitation can be produced from condensation taking place relatively low in the atmosphere and the isentropic charts may be too high to show what is really going on. Several times during the winter 1937–38 such was the case. The isentropic charts showed that condensation could not take place over a certain area, but precipitation of moderate amounts resulted within 24 hours. It was decided that the condensation occurred beneath the insentropic surface that was represented by the chart. This may have been due to a steeper slope of the lower isentropic surfaces or to a relatively higher moisture content in the lower air. A cross section in this area would have shown that while condensation would not occur at high levels, there might have been appreciable lifting in the lower air to produce saturation.

While there is not a really good example of this, the cross section that was just examined, that of January 11, 1938 (fig. 1) illustrates what is meant. The 295° surface is generally about as low as isentropic charts are constructed. It will be noticed that this surface has a very easy slope and that if the air at Omaha were dry we woud not expect any condensation on this surface at Chicago. However, the 287° surface slopes up sharply from 900 meters at Omaha to 2,600 meters at Chicago. Even though the air is relatively dry (40 percent) at Omaha, we have already seen that it will become saturated before it reaches Chicago. The isentropic cross section shows then, not only the slope of one isentropic surface, but the slope of many.

Cross sections also show the layers of moist and dry air. Even if the slopes of the surfaces are found to be about the same throughout the atmosphere, it might be that the air at higher levels would be relatively dry while that in lower levels, below the surface of the isentropic chart, might be relatively moist so that little lifting would result in saturation. Namias in his recent article [3] has ably pointed out the importance of knowing the position of the moist and dry layers for summer forecasting.

STABILITY

The cross section also aids in determining the stability of the atmosphere. When two isentropic charts are constructed, the stability of the layers between them can be determined by finding the difference between the pressures of the upper and lower surfaces. But again this depicts the stability of a very small part of the atmosphere which may not be representative of the whole. An example of this is found on the cross section of March 18 constructed from Salt Lake to Omaha (fig. 2). A stability chart that day was drawn between the 299° and the 303° surfaces. At Omaha a very stable layer was shown between these surfaces near 1 km. However, the air column above 1,500 meters has a lapse rate very close to the dry adiabatic as is shown by the distance between the isotherms of potential temperature. On this particular day the inversion was so pronounced and the air so dry that this steep lapse rate was relatively unimportant, except that it maintained dust to high levels. As far as meteorological phenomena are concerned, a better example is Salt Lake City. If a stability chart had been drawn between the surfaces of 295° and 299°, the layer of air would have been very stable. But on the isentropic cross section it is noted that the air below 3,800 meters, and below the 286° isentropic surface, is conditionally unstable; in fact snow flurries are occurring at the time of the observation.

Conditional stability is shown on the cross sections by the distance between the θ-isotherms. As a rough estimate, conditional equilibrium at the temperatures ranging from 20° to 0° is represented by a distance of about 1,100 meters between the isentropic surfaces of every 5°. If the surfaces are closer together than this, the air is stable; if farther apart, it would be unstable with respect to moist air. If the air were unstable with respect to dry air, the potential temperature would decrease. This seldom happens except close to the ground during the heat of the day. Of course, the cross section can never take the place of the adiabatic chart in determining the stability of a column of air, but the cross section does show the relationship and changes of stability from one station to another.

CONVECTIVE INSTABILITY

The Rossby Diagram is the best chart for determining the convective stability, but it also can be roughly estimated from the cross section by studying the moisture distribution through the vertical. If it is found that through a thin layer the moisture decreases rapidly, then convective instability might be expected. Examining the layer further it might be found that the condensation level at the top was much higher than at the bottom, which would prove that it was convectively unstable. Such was the case in the layer between 2,200 and 2,500 meters at Shreveport February 15, 1938 (fig. 3). At the bottom of this isothermal layer is found a potential temperature of 301° with a condensation temperature of 278°. At the top θ is 304° and T_0 is 266°. This means that particles at the bottom of the layer will have a condensation level at 2,300 meters and those at the top will reach condensation at 3,800 meters. With these air particles streaming up the warm front, it would be expected that this stable layer would tend to become unstable. This is shown by the spreading of the isotherms toward Omaha. Also the solid cloud deck suggests convective equilibrium. Somewhere between San Antonio and Omaha there must have been violent overturning. This is also suggested by the heavy rain and thunderstorms that occurred in northern Texas and southern Oklahoma, Wichita Falls reporting 4.18 inches of rainfall within a period of 12 hours, with a thunderstorm.

RELATIONS TO FRONTS

Rossby has suggested [4] that "air mass boundaries must coincide with isentropic surfaces." During the past winter an effort was made by the Air Mass Section of the Weather Bureau to place fronts along the isentropic surfaces. It was generally found that the fronts followed these surfaces quite consistently. However, a leeway of two or three degrees on either side of the isentropic surface was allowed because of personal and instrumental

[3] Thunderstorm forecasting with the aid of isentropic charts, Bul. Am. Met. Soc., vol. 19, No. 1, 1938.

[4] Isentropic analysis, Bulletin of the American Meteorological Society, vol. 18, No. 6-7, pp. 201.

error. Also on a long north-south cross section there must be some radiational effect.

Fronts are found where there is a packing of the isentropic surfaces above which there is a normal lapse rate. At the surface it would normally be expected that the front would start where the first isentropic surface in the cold air mass cuts the ground. This would probably be approximately true during the heat of the day, but because the aerological observations are taken in the early morn-

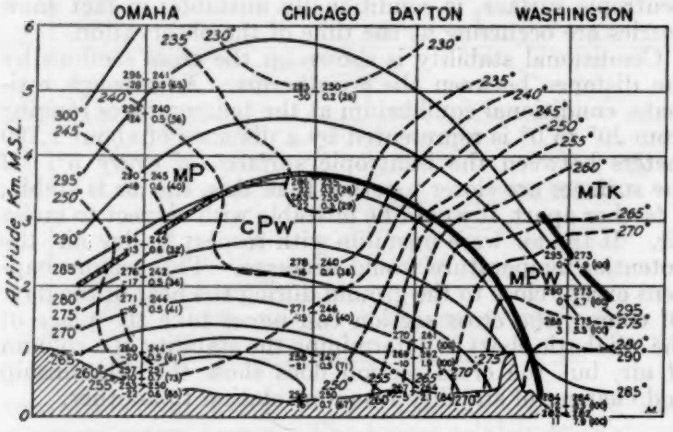


FIGURE 5.—Cross section, Omaha-Washington, January 31, 1938.

ing the effects of radiational cooling in the lower air are prominent, and we found that below 1 km the front passes through the isentropic surfaces at the point of their greatest curvature. This would also be true of tropical air in the winter time as it is cooled by its movement northward.

The above points are illustrated in figure 4, a cross section from Omaha to Washington of February 18, 1938. The front is located on the 293° surface. This is the top of the crowded isotherms and above this the isotherms are well spaced. At Nashville there is practically an isothermal layer in the first 1,000 meters due to cooling so that the potential temperature at the ground is 285° and at 1,100 meters it is 293°. The front was west of Nashville at the time so that it must cut through several surfaces below 1 km. This cold front has an average slope between the surface front and Omaha of 1/300 in the plane of this cross section. Fronts as shown on cross sections along the isentropic surfaces are not as steep as those shown on cross sections where one takes the liberty of drawing fronts through the surfaces. However, there were a few cases during the winter that cold fronts had a very steep slope. One of these is shown in figure 5, an east-west cross section drawn for January 31, 1938. Here again the isentropic surfaces were packed just below the front, and because this is stable continental polar air, there is crowding all through the air mass.

Warm fronts are located on the cross section in much the same manner as cold fronts. Quite often, however, the temperature and wind discontinuity are so weak, on and near the earth's surface, that the front is impossible to find on the synoptic chart, yet it may be very distinct aloft. Such was the case on February 17, 1938, on the cross section from Shreveport to Detroit shown in figure 6. A distinct discontinuity is found on the 293° θ-isotherm at Nashville and Detroit but the location of the front was very doubtful on the synoptic chart because it was so nearly horizontal.

If fronts are drawn along isentropic surfaces, some difficulty is experienced in drawing occluded fronts and fronts aloft. So far we have not been able to get a cross section through a clear-cut occluded front, therefore, no study has been made of them. On the west coast where there is the greatest number of occlusions, the aerological stations are too widely separated to make a detailed study of them. It is the author's belief, and that of his colleagues in the Air Mass Section, that cold and warm type occlusions would have a history such as appears in figure 7. The original cold and warm front would be maintained for awhile as a wave aloft. When the occlusion was new the front might pass through the isentropic surfaces at their greatest curvature, but due to the rapid horizontal mixing in this stable layer the front would soon dissipate. When this occurred a new front would appear on the first isentropic surface that met the ground in the colder air mass.

Although no study has been made of fronts aloft, it is believed that one would be located at the top of an inversion below which the isentropic surfaces sloped sharply. A cold front aloft would appear on the cross section such as pictured in figure 7.

If fronts are placed on isentropic surfaces, then potential temperature becomes an important criterion in determining the boundary properties of air masses. It was noted during the winter 1937–38 that the tropical air warm front usually occurred on the isentropic surfaces between 290° and 293° (for Pacific tropical fronts, 295° to 300°). If the moist air which appears on the 293° surface is called maritime tropical air, then the dry cold air on the same surface that appears at higher altitudes, say about 5 kms, should not be called Polar air. The best name for this air probably is Superior, because it is the same type of air that is found in the warm dry tongues at low altitudes in the southern United States.

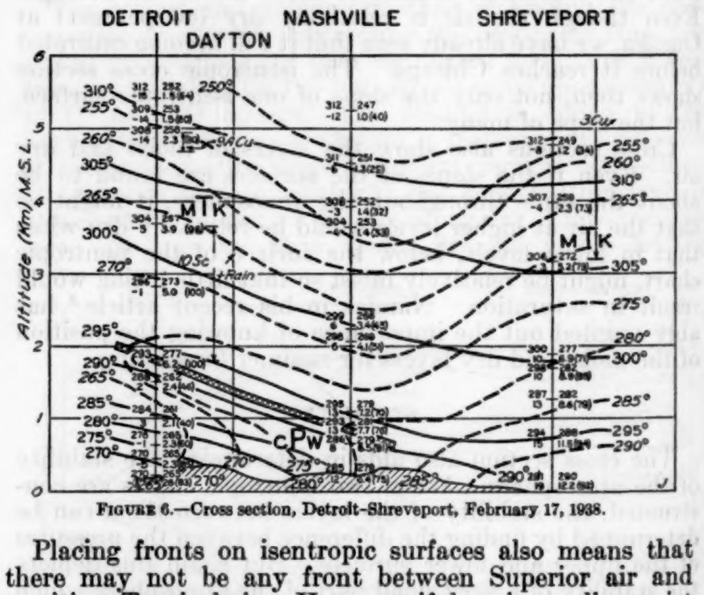


FIGURE 6.—Cross section, Detroit-Shreveport, February 17, 1938.

Placing fronts on isentropic surfaces also means that there may not be any front between Superior air and maritime Tropical air. However, if dry air overlies moist air, then, according to Namias,[5] there would be an inversion and an inactive front between them. A cross section showing no fronts between maritime Tropical air and Superior air is that of February 17 (fig. 6). It is noted that the condensation temperature lines dip sharply from

[5] Structure and Maintenance of Dry Type Moisture Discontinuities not Developed by Subsidence. Mo. WEA. REV., vol. 64, No. 11, November 1936.

Shreveport to Nashville and then curve upward again to Detroit.

In conclusion, the cross section constructed with isotherms of potential temperature and isotherms of condensation temperature has the following advantages over one drawn which uses temperature and specific humidity: first, it has thermodynamic significance because the nearness to saturation of any point can be determined; second, it roughly shows the convective instability of the air as was pointed out on figure 3; third, the slope of many isentropic surfaces is shown; and finally, because fronts follow isentropic surfaces, the position and slope of the fronts which cut the cross section plane can be identified.

The author wishes to express his gratitude to Dr. H. R. Byers for his able guidance and many helpful comments during the preparation of this paper.

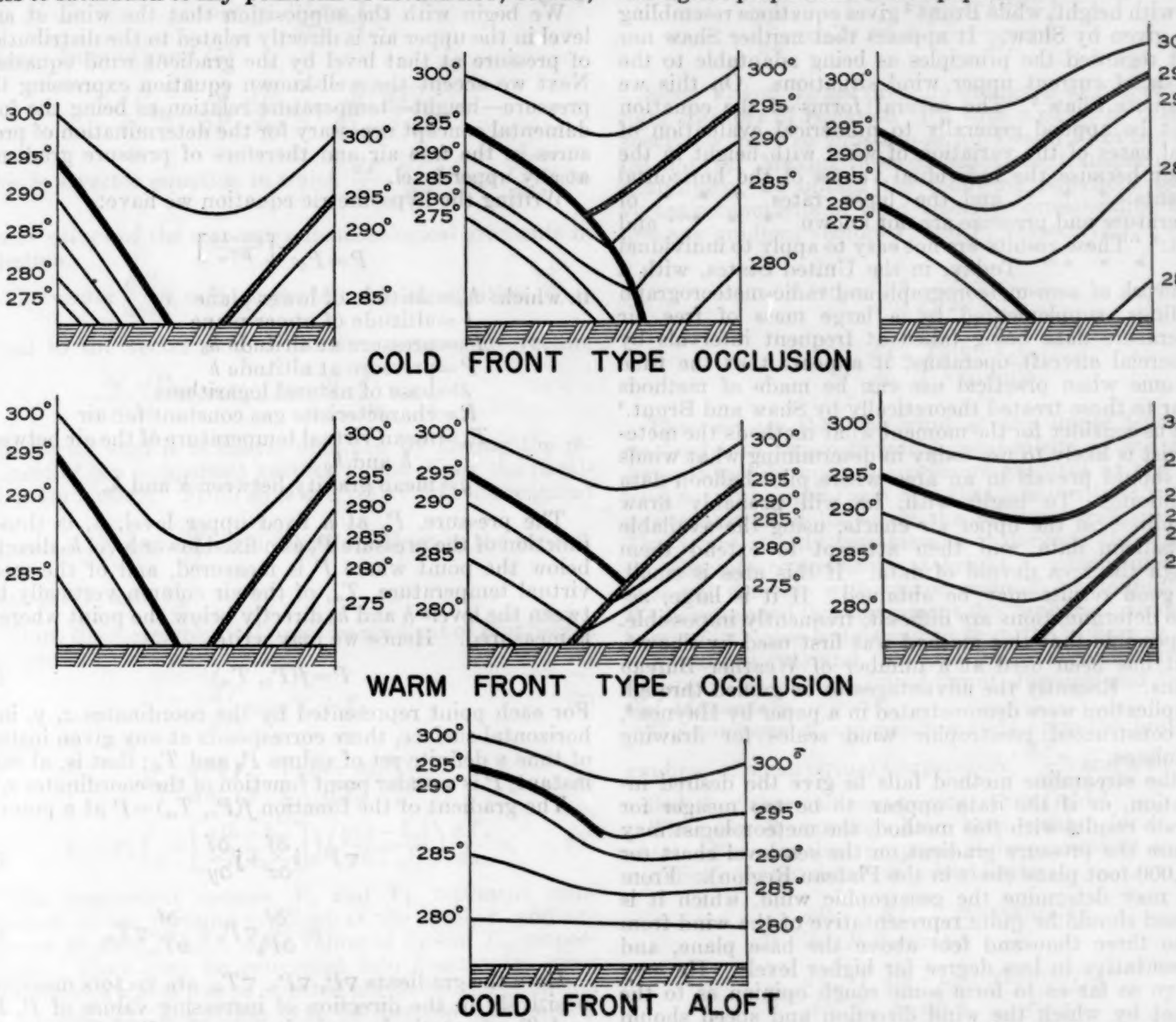


FIGURE 7.—Cross sections showing possible history of frontal positions on isentropic surfaces in cold- and warm-front-type occlusions and cold front a oft.

A PRACTICAL METHOD FOR COMPUTING WINDS ALOFT FROM PRESSURE AND TEMPERATURE FIELDS

By EDWARD M. VERNON and E. V. ASHBURN

[Weather Bureau, Oakland, Calif., May 1938]

The Weather Bureau's network of pilot-balloon observations supplies, as a rule, all the information on winds aloft required for the operation of aircraft. However, it is not an infrequent occurrence for current wind-aloft data to be missing over a large area, due to the presence of low cloud or other weather conditions which interfere with pilot-balloon observations. It is during such weather conditions, which either prevent or greatly limit pilot-balloon observations, that the airplane pilot is most dependent upon information concerning the winds in the upper air. For this reason it has long been desirable to have a practical method for determining the winds aloft at various altitudes without having to rely entirely upon pilot-balloon data.

Meisinger[1] developed a system for the preparation of free air pressure maps which he hoped would provide a basis for the issuance of wind aloft forecasts. The pressure maps were made possible by the reduction of surface pressures to the 2 and 3 kilometer levels. However, his system, notwithstanding its apparent advantages, has received but little practical application.

Shaw[2] gives a formula for computing the variations of wind with height, while Brunt[3] gives equations resembling those given by Shaw. It appears that neither Shaw nor Brunt regarded the principles as being adaptable to the analysis of current upper wind situations. On this we may quote Shaw:[2] "The several forms of the equation cannot be applied generally to numerical evaluation of special cases of the variation of wind with height in the free air because the individual values of the horizontal gradients * * * and the lapse rates * * * of temperature and pressure are not known * * *"; and Brunt:[3] "These results are not easy to apply to individual cases, * * *." Today, in the United States, with a framework of aero-meteorograph and radio-meteorograph soundings, supplemented by a large mass of free air temperature data being taken at frequent intervals by commercial aircraft operators, it appears that the time has come when practical use can be made of methods similar to those treated theoretically by Shaw and Brunt.[4]

Let us consider for the moment what methods the meteorologist is likely to use today in determining what winds aloft should prevail in an area where pilot-balloon data are missing. To begin with, he will probably draw streamlines on the upper air charts, using the available pilot-balloon data, and then attempt to extend them through the area devoid of data. If this area is small, very good results may be obtained. If it is large, accurate determinations are difficult, frequently impossible. It is possible that this method was first used by Shaw[5], and it has been used at a number of Weather Bureau stations. Recently the advantages to be gained through its application were demonstrated in a paper by Haynes[6], who constructed geostrophic wind scales for drawing streamlines.

If the streamline method fails to give the desired information, or if the data appear to be too meager for accurate results with this method, the meteorologist may measure the pressure gradient on the sea level chart (or the 5,000-foot plane chart in the Plateau Region). From it he may determine the geostrophic wind, which it is assumed should be quite representative of the wind from one to three thousand feet above the base plane, and representative in less degree for higher levels. He may then go so far as to form some rough opinion as to the amount by which the wind direction and speed should change with altitude. This approximation he may base simply on averages of the manner in which the wind changes with height, or he may go to the extent of considering qualitatively the effect of the horizontal distribution of temperature on the change of wind with height. Except for the work done by Haurwitz and Meisinger, it seems that no attempt has been made to reduce to a practical routine this last problem of evaluating the effect of temperature distribution. This paper is, therefore, devoted to the problem of developing a practical method for determining the winds aloft by both qualitative and quantitative consideration of the distribution of pressure and temperature. In order to justify the method, which in its final form will be simple and easily applied, it is necessary first to present the fundamental theory underlying its development.

We begin with the supposition that the wind at any level in the upper air is directly related to the distribution of pressure at that level by the gradient wind equation. Next we accept the well-known equation expressing the pressure—height—temperature relation as being the fundamental concept necessary for the determination of pressures in the free air and therefore of pressure gradients at any upper level.

Writing the hypsometric equation we have:

$$P=P_0e^{-\left[\frac{g(h-h_0)}{RT_m}\right]} \tag{1}$$

in which: h_0=altitude of lower plane
h=altitude of upper plane
P_0=pressure at altitude h_0
P=pressure at altitude h
e=base of natural logarithms
R=characteristic gas constant for air
T_m=mean virtual temperature of the air between h and h_0
g=mean gravity between h and h_0

The pressure, P, at a fixed upper level, h, is thus a function of the pressure P_0 at a fixed lower level h_0 directly below the point where P is measured, and of the mean virtual temperature, T_m, of the air column vertically between the levels h and h_0 directly below the point where P is measured. Hence we may write:

$$P=f(P_0, T_m) \tag{2}$$

For each point represented by the coordinates x, y, in a horizontal surface, there corresponds at any given instant of time a definite set of values P_0 and T_m; that is, at each instant, P is a scalar point function of the coordinates x, y.

The gradient of the function $f(P_0, T_m)=P$ at a point is

$$\nabla P=\mathbf{i}\frac{\partial f}{\partial x}+\mathbf{j}\frac{\partial f}{\partial y} \tag{3}$$

$$=\frac{\partial f}{\partial P_0}\nabla P_0+\frac{\partial f}{\partial T_m}\nabla T_m \tag{4}$$

Here the gradients ∇P, ∇P_0, ∇T_m, are vectors measured positively in the direction of increasing values of P, P_0, and T_m, respectively, oppositely to the direction customarily used in meteorology for the gradient. Equation (4) holds equally well if meteorological gradients are used for the mathematical gradients, since on multiplying both sides of the equation by minus one, the appropriate meteorological gradients may be substituted for $-\nabla P$, $-\nabla P_0$, and $-\nabla T_m$.

The fields of pressure, P and P_0, can be represented by isobars, while the field of mean temperature of the air column, T_m, can be represented by isotherms. If $\boldsymbol{n}_1$ and $\boldsymbol{n}_2$ are unit vectors at a point (x, y) in the fields of P and P_0 measured normal to the isobars in the direction of decreasing values of P and P_0, respectively, and $\boldsymbol{n}_3$ is a unit vector at the point (x, y) in the field of T_m measured

[1] MONTHLY WEATHER REVIEW, Supplement No. 21, 1922; The Preparation and Significance of Free Air Pressure Maps for the Eastern United States.
[2] Manual of Meteorology, vol. IV (1931) pp. 196-7.
[3] Physical and Dynamical Meteorology, pp. 200-201.
[4] B. Haurwitz of the Canadian Meteorological Service has taken the equations presented by Brunt and worked out a method of applying them to actual cases.
[5] Manual of Meteorology, vol. IV (1931), pp. 212-3.
[6] Upper Wind Forecasting; Monthly Weather Review, 66 : 4-6, January 1938.

normal to the isotherms in the direction of decreasing values of T_m, then

$$\left.\begin{aligned} -\nabla P &= \frac{dP}{dn_1}\boldsymbol{n}_1 \\ -\nabla P_0 &= \frac{dP_0}{dn_2}\boldsymbol{n}_2 \\ -\nabla T_m &= \frac{dT_m}{dn_3}\boldsymbol{n}_3 \end{aligned}\right\} \tag{5}$$

whence from (4) and (5)

$$\frac{dP}{dn_1}\boldsymbol{n}_1 = \frac{\partial f}{\partial P_0}\frac{dP_0}{dn_2}\boldsymbol{n}_2 + \frac{\partial f}{\partial T_m}\frac{dT_m}{dn_3}\boldsymbol{n}_3 \tag{6}$$

This is a vector equation in which $\frac{dP}{dn_1}$, $\frac{dP_0}{dn_2}$, and $\frac{dT_m}{dn_3}$ are scalar values of the respective meteorological gradients in question.

The vector $\frac{dP}{dn_1}\boldsymbol{n}_1 \equiv \boldsymbol{V}_1$ on the left side of equation (6) is equal to the vector sum of the two component vectors $\frac{\partial f}{\partial P_0}\frac{dP_0}{dn_2}\boldsymbol{n}_2 \equiv \boldsymbol{V}_2$ and $\frac{\partial f}{\partial T_m}\frac{dT_m}{dn_3}\boldsymbol{n}_3 \equiv \boldsymbol{V}_3$.

The vector sum is of course obtained by finding the resultant of the component vectors $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ by the parallelogram method. From equation (1) we find the required values of $\frac{\partial f}{\partial P_0}$ and $\frac{\partial f}{\partial T_m}$ and substitute them in the expressions for $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$.

Thus, the meteorological pressure gradient of P at height h is given by the vector sum,

$$\frac{dP}{dn_1}\boldsymbol{n}_1 = \boldsymbol{V}_2 + \boldsymbol{V}_3 \tag{7}$$

where

$$\boldsymbol{V}_2 = \frac{dP_0}{dn_2}\left(e^{-\left[\frac{g(h-h_0)}{RT_m}\right]}\right)\boldsymbol{n}_2 \tag{8}$$

$$\boldsymbol{V}_3 = P_0\left(e^{-\left[\frac{g(h-h_0)}{RT_m}\right]}\right)\left(\frac{g(h-h_0)}{RT_m^2}\right)\frac{dT_m}{dn_3}\boldsymbol{n}_3 \tag{9}$$

The component vectors, $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$, represent components of the pressure gradient at the level, h, and are always directed toward lower values of P_0 and T_m, respectively. They may be converted into geostrophic wind components which will be directed normal to the gradients of P_0 and T_m, i. e., they will be directed cyclonically about lower values of P_0 and T_m respectively.

The equation for the geostrophic wind is written,

$$\frac{dP}{dn} = v2\omega\rho\sin\phi \tag{10}$$

in which dP/dn is the horizontal pressure gradient, v the wind speed, ω the angular velocity of rotation of the earth, ϕ the latitude, and ρ the density of the air.

But by the gas equation,

$$\rho = \frac{P}{RT} \tag{11}$$

in which P and T are the pressure and temperature at the level under consideration. From equation (1), P may be expressed in terms of P_0, whence (11) becomes,

$$\rho = \frac{P_0 e^{\left(\frac{-g(h-h_0)}{RT_m}\right)}}{RT} \tag{12}$$

and (10) becomes,

$$\frac{dP}{dn} = v\,2\omega\sin\phi\,\frac{P_0 e^{\left(\frac{-g(h-h_0)}{RT_m}\right)}}{RT} \tag{13}$$

Since $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ are pressure gradients at height h, the right member of equation (13) with v equal to v_2, v_3, respectively, may be substituted for $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ in equations (8) and (9). Making these substitutions, transposing, and simplifying, we obtain the following equations for the vector components of wind velocity corresponding to the pressure gradient vectors $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$, respectively.

$$v_2 = \frac{dP_0}{dn_2}.\frac{RT}{P_0\,2\omega\sin\phi} \tag{14}$$

$$v_3 = \frac{dT_m}{dn_3}\,\frac{Tg(h-h_0)}{T_m^2\,2\omega\sin\phi} \tag{15}$$

Thus we see that the wind at any upper level h, is resolved into two orthogonal components v_2 and v_3. v_2 depends largely upon the pressure gradient at the lower level h_0. It has been said of v_2 that it is identical with the geostrophic wind based on the pressure gradient at h_0. This is not strictly true because it depends also upon T, the absolute temperature at height h, which, of course, does not coincide with temperature T_0 prevailing at h_0. We have termed this component the "isobaric" component because its value is determined from the isobars at h_0.

Equations (14) and (15) also follow immediately from equations (8) on page 200 of Brunt, *Physical and Dynamical Meteorology*.

The component, v_3 depends mainly upon the horizontal gradient of mean virtual temperature, $\frac{dT_m}{dn_3}$, and is therefore called the "thermal" component, after Gold.[7]

Thus far all equations have been written for C. G. S. units. For practical purposes it is convenient to write equations (14) and (15) in mixed units:

$$v_2 = \frac{dP_0}{dn_2}\,\frac{RT}{P_0\,2\omega\sin\phi}\,\frac{.00000069756}{K} \tag{16}$$

$$v_3 = \frac{dT_m}{dn_3}\,\frac{T\,g(h-h_0)}{T_m^2\,2\omega\sin\phi}\,\frac{.0000038754}{K} \tag{17}$$

Here, $R = 2.87\times10^6$, $\omega = \frac{2\pi}{86{,}164}$, ϕ, g, h, and h_0 have the same significance as in equation (1) and are in C. G. S. units, while

v_2 and v_3 = velocity in miles per hour.
dP_0 = Isobaric interval at h_0, in units of 0.05 in mercury.
dT_m = Isotherm (dT_m) interval in units of 5° F.
T = Absolute temperature at height, h.

[7] Shaw. Manual of Meteorology, vol. IV (1931); p. 202.

dn_2 and dn_3 = millimeters on map between isobars or isotherms. (If the constant, K, is omitted dn_2 and dn_3 are in statute miles.)

P_0 = Pressure at h_0, in hundredths inch mercury, written without decimal.

K = a constant equal to the number of miles represented by 1 mm at latitude ϕ on the particular map projection used.[8]

SCALES FOR MEASURING ISOBARIC AND THERMAL COMPONENTS

Wind scales for measuring the isobaric and thermal components are constructed from equations (16) and (17). They may be used on charts having isobars drawn for P_0 and isotherms drawn for T_m. Figure 1 shows a scale for working from the 5,000-foot plane pressure chart to the 10,000-, the 14,000-, and the 20,000-foot levels. Figure 2 shows a scale for working from the sea level pressure map to the 5,000-, the 10,000-, the 14,000-, and the 20,000-foot levels. In the preparation of the scales, g was set constant at the value obtaining between h and h_0 at latitude 40° N. with only negligible error resulting. The values used for T, T_m, and P_0 were taken from the standard atmosphere and used as constants, for each scale depending only on the appropriate value of h and h_0. Some small errors result from the use of constant values for these elements, whenever T, T_m, and P_0 depart from the standard atmosphere values. However, by using the particular values of T, T_m, and P_0 pertinent to the value of h and h_0, the magnitude of these errors is kept at a minimum. They are consequently quite small and usually negligible. The corrections are calculated as follows:

Corrections for temperature.—Assume that the actual temperature, T', obtaining at height h will depart from the standard atmosphere value of T, used in constructing the scale, in the same amount as the actual value of mean temperature, T'_m, departs from the standard atmosphere value of T_m used in the construction of the scale. Let the departure from the standard atmosphere value of T_m be ΔT_m. Then,

$$T' = T + \Delta T_m$$
$$T'_m = T_m + \Delta T_m$$

It follows from equations (16) and (17) that the percentages of error caused by the departure of the actual temperature from the standard atmosphere value are given by:

(*a*) For the isobaric component,

$$\text{Percentage of error} = \frac{\Delta v_2}{v_2} = 100\left(\frac{\Delta T_m}{T}\right)$$

The correction is therefore added for positive values of ΔT_m, i. e., when T'_m exceeds T_m.

(*b*) For the thermal component,

$$\text{Percentage of error} = \frac{\Delta v_3}{v_3} = -100\left[-\frac{T+\Delta T_m}{(T_m+\Delta T_m)^2}+\frac{T}{T_m^{\,2}}\right]\frac{T_m^{\,2}}{T}$$

The percent of error can now be calculated, since T and T_m are the standard atmosphere values used in constructing the scales, while ΔT_m can be taken from the chart. Appropriate corrections for ΔT_m have been calculated and entered on the scales. It will be noted that they are quite small and that they will usually be negligible.

[8] W. R. Gregg and I. R. Tannehill, International Standard Projections for Meteorological Charts, MONTHLY WEATHER REVIEW, 65: 411-415, December 1937.

Correction for pressure.—The only pressure used in constructing the scales was P_0, which is subject to direct observation and for which no substitution is therefore necessary. Let the actual pressure, P'_0, depart by the amount, ΔP_0, from the standard atmosphere value of P_0 used in constructing the scale. Then,

$$P'_0 = P_0 + \Delta P_0$$

It follows from equations (16) and (17) that the percentage of error caused by the departure of pressure from the standard atmosphere value is given by:

(*a*) For the isobaric component,

$$\text{Percentage of error} = -100\left(\frac{\Delta P_0}{P_0}\right)$$

Corrections for ΔP_0 have been calculated and entered on the scale for the isobaric component, with explicit directions for their application. It will be observed that they are small and usually negligible. There is no correction for ΔP_0 on the scale for the thermal component.

DESCRIPTION AND USE OF THE WIND SCALES

The scales are constructed by plotting curves for latitudes 30°, 40°, and 50°, based on coordinates of wind velocity in miles per hour and distances, dn_2 and dn_3, between successive isobars, or isotherms, in millimeters, as computed by equations (16) and (17).

Scale for thermal component.—The upper half of figure 1 is a scale for measuring the velocity of the thermal component when the 5,000-foot plane is used as a base, while the upper half of figure 2 is the thermal component scale for use with the sea-level chart as a base. The distances between successive 5° F. isotherms of T_m are laid off vertically as ordinates, positively upward from the x-axis which is marked "zero line" on the figure. From the synoptic chart, the distance between isotherms may be measured with a ruler, or simply marked off on the edge of a strip of paper; then, on figure 1, the point which lies at that distance from the zero line, and on the appropriate latitude curve, is readily located, and vertically above it on the appropriate velocity scale the velocity of the thermal component is read off. A small correction for departure of T_m from the standard value may be applied by referring to the corrections noted on the diagram. This velocity component should be entered on the chart as a vector drawn to any convenient scale, and placed on the synoptic chart at the point under consideration.

The vector for the thermal component, thus determined, must *always* be parallel to the isotherm passing through the point under consideration, and must be directed *cyclonically* about lower values of T_m, i. e., must be drawn so that lower temperatures are to the left of an observer with back to the wind.

It is important to understand that if the velocity of the thermal component for the 10,000-foot plane is desired, the isotherms used with the scale must represent the horizontal distribution of mean temperature applying between the base plane and the 10,000-foot plane. Likewise, if the velocity of the thermal component on the 14,000-foot plane is desired, the isotherms must be drawn for mean temperatures applying between the base plane and the 14,000-foot plane, etc.

Scale for isobaric component.—Scales for determining the velocity of the isobaric component are shown in the lower half of figures 1 and 2, the former for use with the base chart at 5,000 feet and latter with the base chart at sea level. The isobaric interval is 0.05 inch of mercury

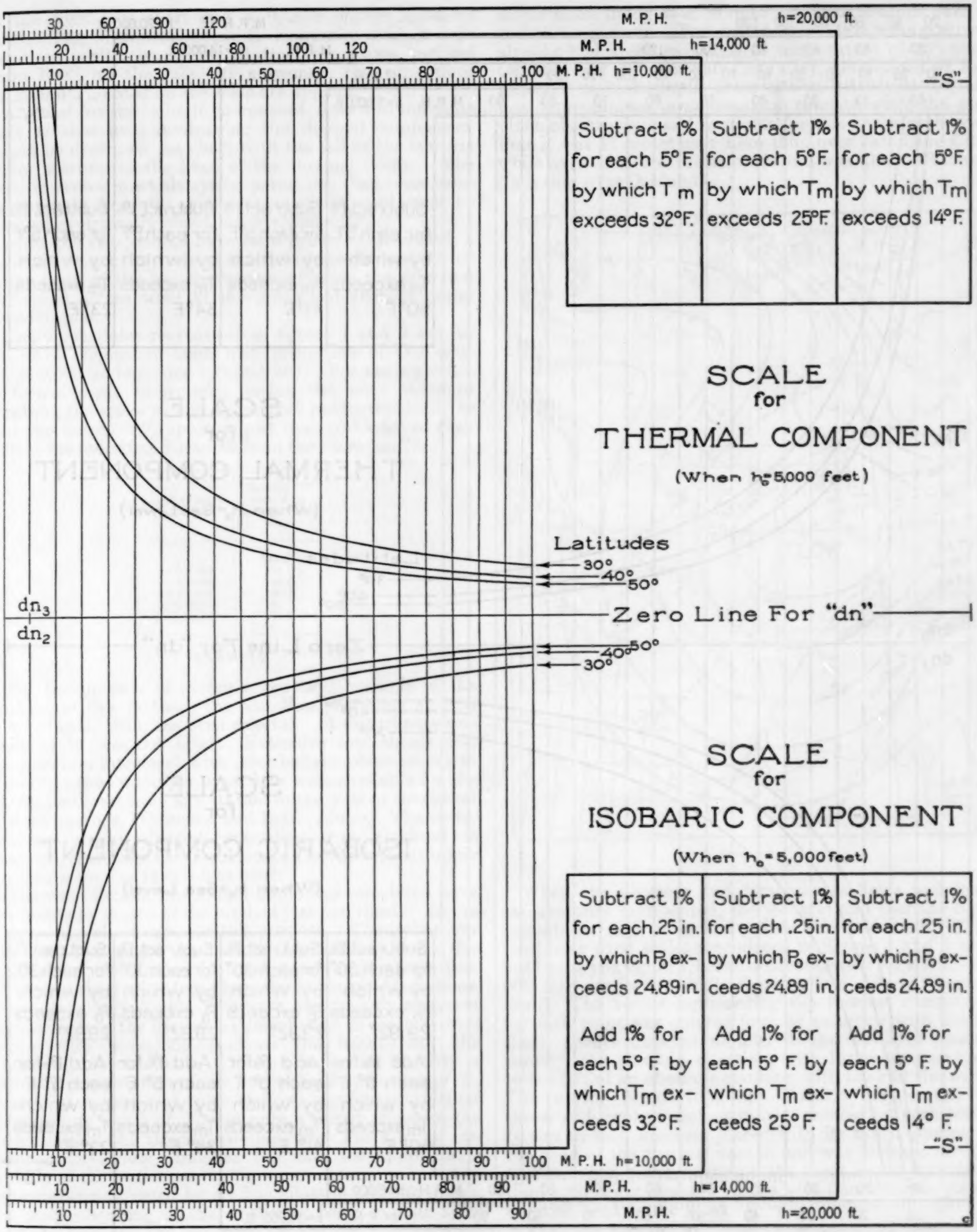

M. P. H. h=20,000 ft.
M. P. H. h=14,000 ft.
M. P. H. h=10,000 ft.
"S"
Subtract 1% for each 5° F. by which T_m exceeds 32° F.
Subtract 1% for each 5° F. by which T_m exceeds 25° F.
Subtract 1% for each 5° F. by which T_m exceeds 14° F.
SCALE for THERMAL COMPONENT
(When h_0=5,000 feet)
Latitudes
30°
40°
50°
dn_3
dn_2
Zero Line For "dn"
50°
40°
30°
SCALE for ISOBARIC COMPONENT
(When h_0=5,000 feet)
Subtract 1% for each .25 in. by which P_0 exceeds 24.89 in.
Add 1% for each 5° F. by which T_m exceeds 32° F.
Subtract 1% for each .25 in. by which P_0 exceeds 24.89 in.
Add 1% for each 5° F. by which T_m exceeds 25° F.
Subtract 1% for each .25 in. by which P_0 exceeds 24.89 in.
Add 1% for each 5° F. by which T_m exceeds 14° F.
"S"
M. P. H. h=10,000 ft.
M. P. H. h=14,000 ft.
M. P. H. h=20,000 ft.

Figure 1.

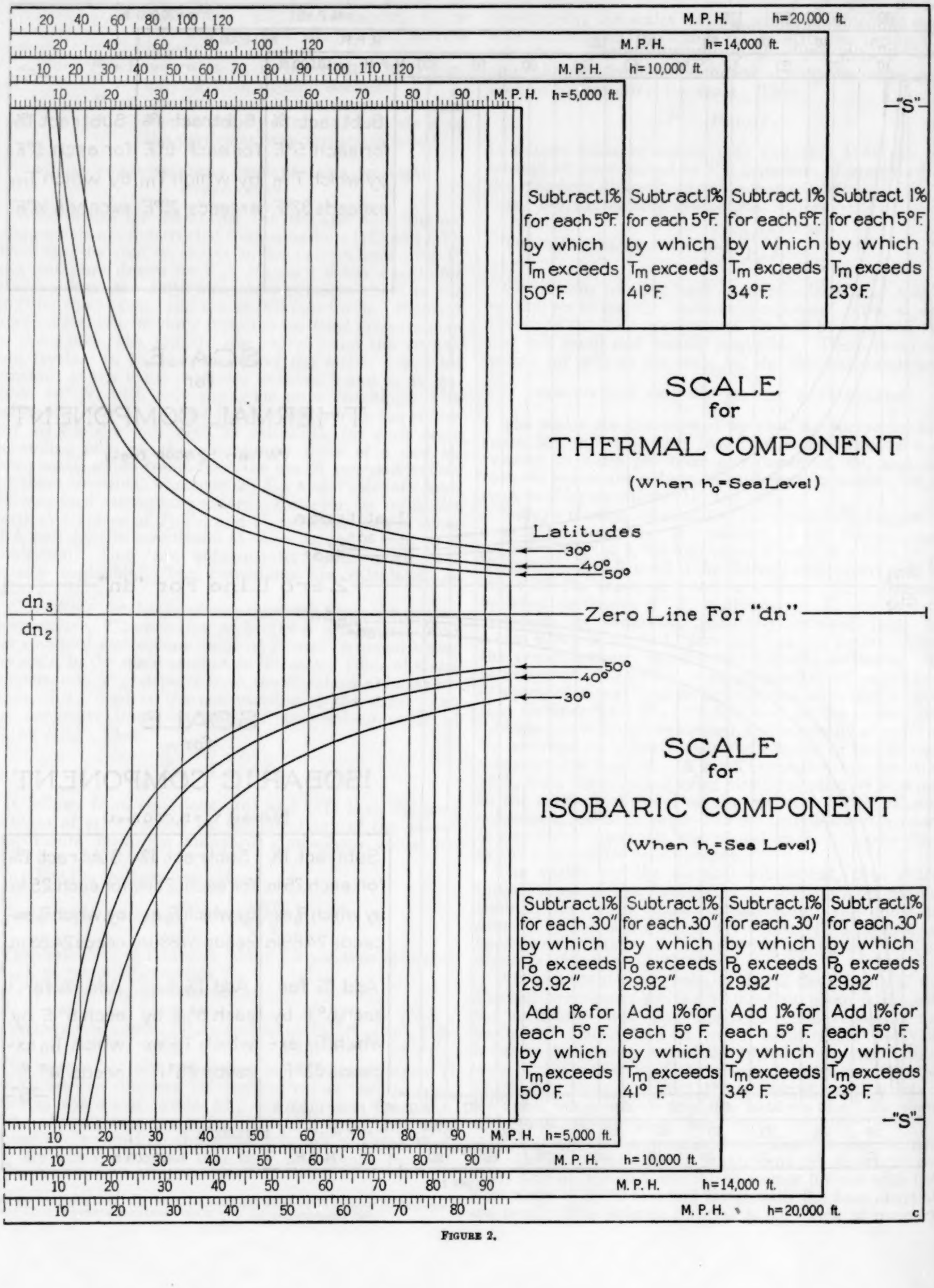

M. P. H. h=20,000 ft.
M. P. H. h=14,000 ft.
M. P. H. h=10,000 ft.
M. P. H. h=5,000 ft.
"S"
Subtract 1% for each 5°F. by which T_m exceeds 50°F.
Subtract 1% for each 5°F. by which T_m exceeds 41°F.
Subtract 1% for each 5°F. by which T_m exceeds 34°F.
Subtract 1% for each 5°F. by which T_m exceeds 23°F.
SCALE for THERMAL COMPONENT
(When h_o=Sea Level)
Latitudes
30°
40°
50°
dn_3
dn_2
Zero Line For "dn"
50°
40°
30°
SCALE for ISOBARIC COMPONENT
(When h_o=Sea Level)
Subtract 1% for each .30" by which P_o exceeds 29.92"
Add 1% for each 5° F. by which T_m exceeds 50° F.
Add 1% for each 5° F. by which T_m exceeds 41° F.
Add 1% for each 5° F. by which T_m exceeds 34° F.
Add 1% for each 5° F. by which T_m exceeds 23° F.
"S"

FIGURE 2.

on the 5,000-foot chart and 0.10 inch on the sea-level chart. The distances between successive isobars are measured positively downward from the x-axis, marked "zero line" on the sale. If necessary, the corrections for P_0 and T_m noted on the scale are applied.

A vector for the isobaric component, drawn to the same scale as that used in drawing the thermal component, should be drawn on the chart with the tail of the isobaric vector starting at the head of the thermal vector. The isobaric vector must always be parallel to the isobar passing through the point under consideration, and must be directed cyclonically about lower values of P_0.

After the two vectors have been drawn as described, a resultant vector drawn from the tail of the thermal vector to the head of the isobaric vector will give the direction and speed of the wind at the point and altitude under consideration.

The wind scales reproduced in figures 1 and 2 are for use on a conformal conic map projection of the scale 1: 5,000,000 at latitudes 30° and 60°. For use on other conformal conic projections having the same standard parallels, the scales should be reduced photographically so that the mark, "S", appearing at the right edge of each scale is the following distances from the "zero line":

Scale of map projection	Distance "S" should be from the "zero line"
	mm
1:5,000,000	100
1:7,500,000	66.7
1:8,300,000	60.2
1:10,000,000	50
1:15,000,000	33.3

EXAMPLE

For the purpose of giving a practical example of the working of this method, the situation prevailing at 7:30 a. m. May 2, 1938, has been selected. A disturbance was centered in western Utah. Extensive low clouds and precipitation interfered with pilot balloon observations to the extent that no upper wind data were available for the 14,000-foot level from any station to the west or southwest of Rock Springs, Wyoming, and Boise, Idaho. The entire Oakland airway district, extending from Oakland to Medford, Salt Lake City, and Burbank, was without upper wind data for the 14,000-foot level.

The wind for the 14,000-foot plane was calculated for a few points by means of the method just described. Figure 3 shows the chart used for this purpose. The isobars for the 5,000-foot plane are in solid black lines, drawn for intervals of 0.05 inch. Isotherms for temperatures prevailing on the 10,000-foot plane are in broken black lines, drawn for every 5° F. They are assumed to represent approximately the horizontal distribution of mean virtual temperature prevailing between the 5,000- and the 14,000-foot levels. It is far more important to have a correct representation of the horizontal distribution of T_m than to have the exact value of T_m at any one point, since the absolute value of T_m has only a minor effect on the magnitude of the thermal component. The 4 a. m. airplane observations furnished the data for approximate spacing of the isotherms, but it was necessary to resort to temperatures reported by air line pilots in order to obtain the proper spacing of the isotherms between Salt Lake City and Oakland and between Oakland and Portland.

In using air line temperature reports it is not generally advisable to use the actual values of temperature reported, but rather to use the horizontal gradient as shown by a single plane flying at a more or less fixed altitude over a rather long route. For instance, in this example, we already had absolute values of temperature of 25° over Oakland and 29° over Salt Lake City, determined by the airplane meteorograph observations. Analysis of air line temperatures, synchronizing roughly with the airplane observations and available for this analysis, showed that it was 4° colder over Elko than over Salt Lake City while over Medford the temperature was about 6° lower than that over Oakland.

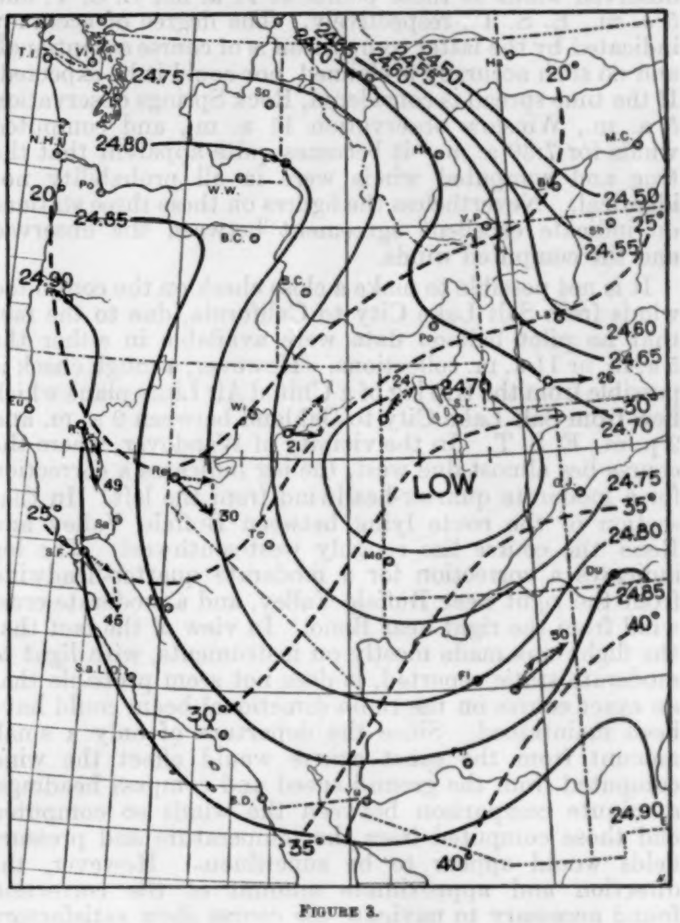


FIGURE 3.

When the pressure and temperature fields had been satisfactorily represented, the isobaric and thermal components for each of several points were scaled off. (The particular wind scales reproduced in figures 1 and 2 cannot be used on figure 3, because the scales are for a 1: 5,000,000 map projection while figure 3 is a different projection.) The vector representing the thermal component for each point was entered first, as an arrow with dotted shaft, always directed parallel to the isotherm passing through the point in question, with lower temperatures to the left of an observer standing with back to the wind. The vector representing the isobaric component, an arrow with broken shaft, was next entered for each point. It was in each instance placed with its tail beginning at the head of the thermal vector, and was directed parallel to the isobar passing through the point under consideration, with lower pressure on the left of an observer standing with back to the wind.

With the thermal and isobaric components thus represented, the resultant vector for each point was drawn from the tail of the thermal vector to the head of the isobaric vector. Drawn in this way the resultant vector

gives the direction and speed of the wind at the point and altitude under consideration. In figure 3 the velocity represented by the resultant vector has been entered near the head of that vector.

In comparing the computed winds with the winds shown by the next scheduled pilot balloon observations it is interesting to note that the computed wind for Redding was north northwest 49 m. p. h. while the observed wind was north northwest 46 m. p. h. The computed winds for Winslow and Rock Springs were the same as the observed winds at those points at 11 a. m., E. S. T. and 5 a. m., E. S. T., respectively. The degree of accuracy indicated by the latter comparison is of course exceptional, and no such accuracy is claimed, nor could it be expected. If the time spread is considered, Rock Springs observation 5 a. m., Winslow observation 11 a. m., and computed winds for 7:30 a. m.—it becomes quite apparent that the true and computed winds were in all probability not identical. Nevertheless the figures on these three stations do indicate excellent agreement between the observed and the computed winds.

It is not possible to make a close check on the computed winds from Salt Lake City to California, due to the fact that no pilot balloon data were available in either the 5 a. m. or 11 a. m. collections. However, a rough check is possible from the trip log of a United Air Lines plane which flew from Salt Lake City to Oakland between 9 a. m. and 2 p. m., E. S. T. In the vicinity of Wendover, where the course lies almost due west, the log indicates a correction for a moderate quarter-headwind from the left. In that section of the route lying between Buffalo Valley and Reno the course lies roughly west-southwest. The log indicates a correction for a moderate quarter-headwind from the right near Buffalo Valley, and a moderate cross wind from the right near Reno. In view of the fact that the flight was made mostly on instruments, with light to moderate static reported, it does not seem probable that an exact course on the radio directional beam could have been maintained. Since the departure of only a small amount from the exact course would affect the wind computed from the ground speed and compass headings, a minute comparison between the winds so computed and those computed from the temperature and pressure fields would appear to be superfluous. However, the direction and approximate amount of the correction found necessary to navigate the course show satisfactory agreement with the winds computed from the pressure and temperature fields.

Before passing figure 3 it is interesting to observe that the wind at any level between the 5,000-foot plane and the 14,000-foot plane should be represented by a vector drawn from some point on the shaft of the thermal vector to the point of intersection of the isobaric and resultant vectors.

Similar methods can be used with the sea level pressure map in flat country, provided isotherms are superimposed on the pressure chart, representing the field of mean temperature applying between the surface and the altitude for which winds are to be computed. The scale reproduced in figure 2 has been prepared for use in conjunction with the sea level chart.

It will be interesting to some to know that the scales for the isobaric component may be used as geostrophic wind scales for the surface or sea level chart, and that if the corrections indicated for ΔP_0 and ΔT_m are applied, the scales so used will be highly accurate. In using the isobaric scale for this purpose, T_m should be taken as the surface temperature at the point where the wind is to be measured.

Theoretically, the wind scales should enable us to compute the winds aloft with a close degree of precision. In fact, from purely static considerations, the computations should be nearly exact. Difficulties will be encountered, however, and it is fitting that a few of them should be mentioned here.

Representation of the temperature field is likely to be the most common and most bothersome source of trouble. As indicated earlier, it is hoped that at centrally located airway meteorological offices there will be on hand sufficient temperature data to enable the meteorologist to obtain a creditable and satisfactory picture of the distribution of temperature at least once and possibly several times each day. Experience in drawing isotherms of T_m will gradually lead to greater accuracy than one can hope to attain at the first attempt. For example, it will be observed that in frontal zones the isotherms should be relatively crowded; that strong winds reported, although by only an isolated pilot balloon observation, usually indicate a relative crowding of the isotherms in that vicinity unless the amount of wind can be accounted for by the existing surface pressure gradient. This latter point holds so well that it is possible to determine the free air horizontal temperature gradient provided the surface pressure gradient and the free air winds are known.

If the temperature field is properly represented, the greatest source of error will have been eliminated. Smaller errors are always possible as a result of the fact that both the cyclostrophic and the isallobaric components of the wind flow have been omitted. We have assumed balanced, straight-line flow of the air. It is believed that the resulting errors will be very small and as a rule negligible, inasmuch as these components in the free air are small as compared to the speed of modern aircraft. Furthermore, the two components tend to act in the opposite directions and therefore to cancel one another: an isallobaric component to the left necessarily being associated with and bringing about a cyclostrophic component to the right, while an isallobaric component to the right should be associated with a cyclostrophic component to the left.

The influences of turbulence, friction, convection, and terrain (all closely related) have not been taken into account but should not prove too troublesome because the method here presented is designed to be used mainly for computing winds at altitudes where these are minor factors.

Finally, it should be emphasized that the method here suggested is not one for forecasting upper winds, but rather one for determining what upper winds should prevail at a given moment, past or present.

In closing, the authors wish to acknowledge the assistance of L. P. Harrison, at the Central Office of the Weather Bureau, in constructing a proof for equation (7).

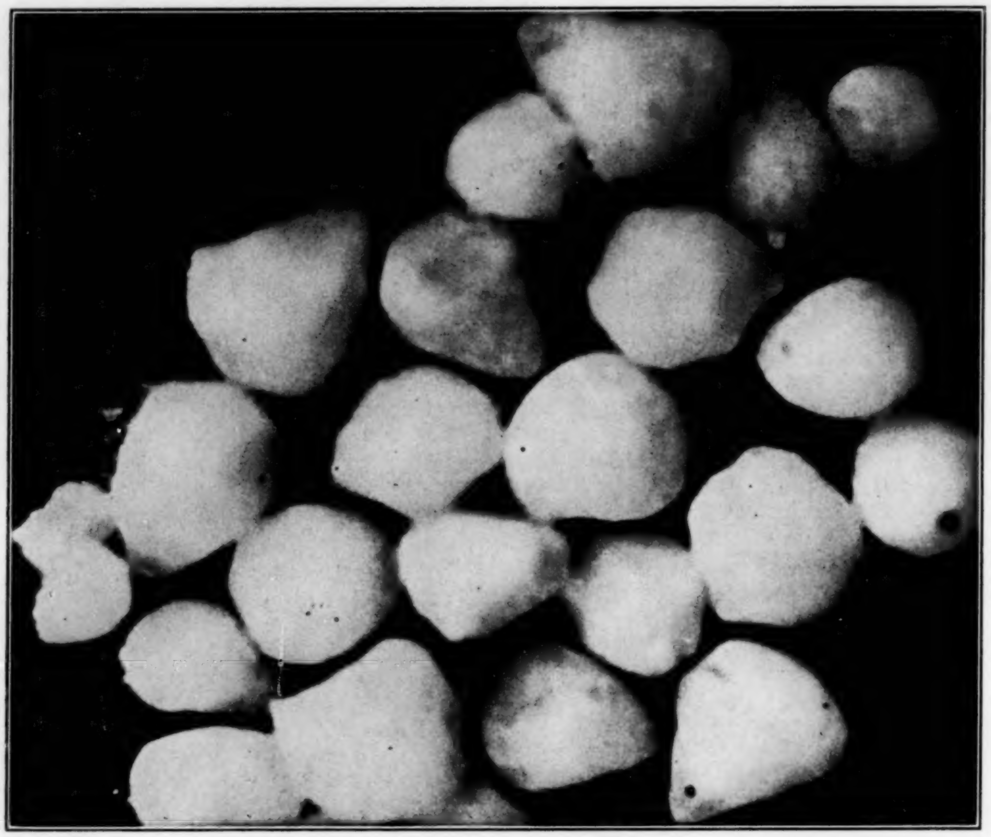


FIGURE 1.—Hailstones (actual size) at Washington, D. C., April 29, 1938.

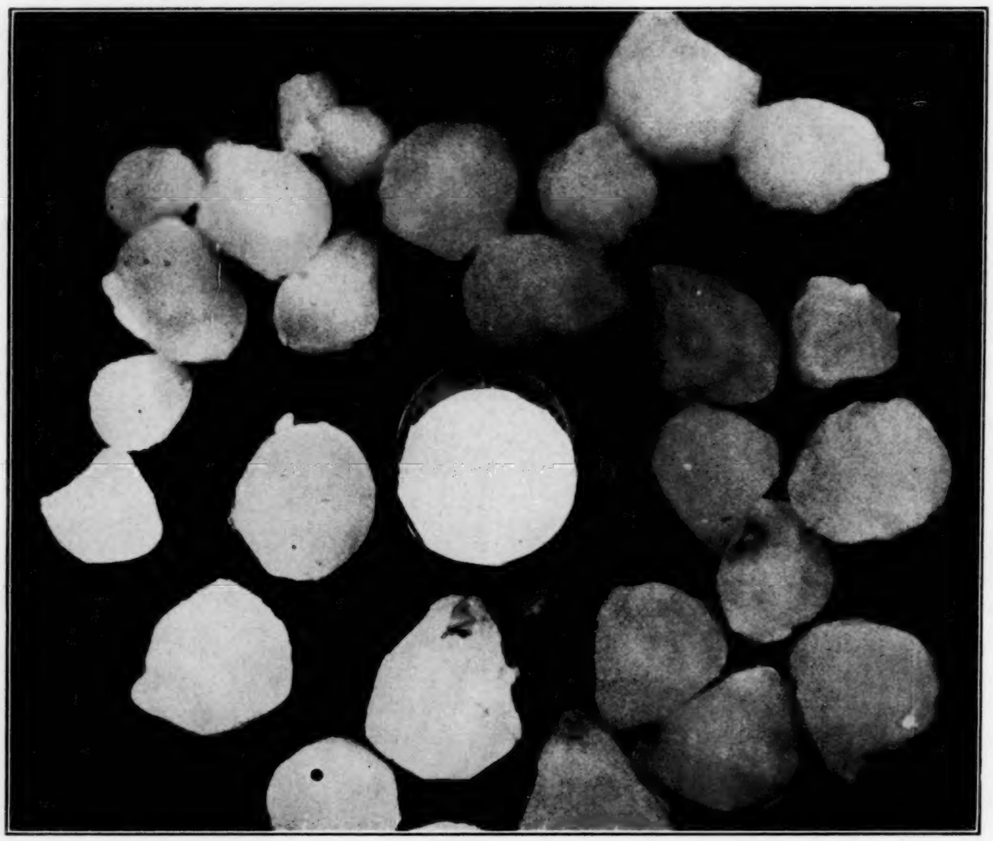


FIGURE 2.—Hailstones (actual size) at Washington, D. C., April 29, 1938. For comparison of relative size, note the pile of quarter dollars.

THE HAILSTORM OF APRIL 1938 AT WASHINGTON, D. C.

UNUSUAL FALL OF LARGE HAILSTONES AT WASHINGTON, D. C.

By GILES SLOCUM

[Weather Bureau, Washington, D. C., May 1938]

On April 29, 1938, Washington and its vicinity were visited by a destructive hailstorm. Damage was estimated at $100,000. At the Weather Bureau, two windows were broken, several automobile tops punctured, and leaves and twigs stripped off trees.

The storm approached the Weather Bureau office from the west at about 12:15 p. m., E. S. T., with rain beginning about 12:30 p. m. The rainfall soon became heavy and a few hailstones were seen mixed with the rain. Then larger stones, unaccompanied by noticeable rain, commenced to fall at about 12:36, with the wind becoming strong for a few seconds.

After the storm, some of the hailstones were picked up and in the majority of cases found to be roughly hemispherical at one end and conical at the other, the longest axis passing through the vertex of the cone—the shape for maximum streamlining. Figures 1 and 2 show some of the stones gathered after they had partially melted. In both photographs, the stones are shown approximately in natural size. The circle in the center of figure 2, for comparison, is the size of a pile of quarter dollars. The largest stones measured at the Weather Bureau were somewhat less than an inch and a half in their longest dimension, but some the size of baseballs, according to reports, fell in northeast and southeast sections of the city and at Bolling Field airport.

Falls of damaging hail in Washington are rare, and if the report of stones as large as baseballs in outlying portions of the city is authentic, this ranks among the heaviest hailstorms Washington has ever experienced.

THE FORMATION OF IRREGULARLY SHAPED HAILSTONES

By DAVID L. ARENBERG

[Blue Hill Observatory, Milton, Mass., August 1938]

On April 29, 1938, the city of Washington and its suburbs were treated to a display of hail that surpassed previous records in that locality. Not only because of the financial losses estimated at $100,000 to greenhouses, automobiles, crops, and buildings, but because of the unusual shape of the icy missiles, the occasion merits attention. As the storm occurred during the annual meeting of the Meteorological Section of the American Geophysical Union, meteorologists were not lacking to examine the effects.

There were two distinct periods of hail. Rain which began to pour from a thunderstorm that had built up in the northwest at 12:30 p. m., changed to hail at 12:32, to rain 2 minutes later, and back to hail at 12:36 which lasted until 12:54. In the first stage the stones were few and small, about an eighth of an inch across, displaying no concentric shells, and were irregularly shaped like kernels of corn.

The second period was more severe and caused all the destruction, with hailstones whitening the ground and piling up a few inches deep in gutters and depressions. A size of three-fourths inch was common and many hailstones were measured over an inch in length. The majority were triangular pyramids with distinct faces and dihedral angles of various sizes and spherical bases. Quadrilateral, pentagonal, and other polygonal forms were also frequent; so that, in general, the shape was that of kernels of corn, although much larger and with structural features additional to those of the first type. The shorter axis varied from about two-thirds to one-third that of the longer which was along the altitude of the pyramids. The outer layers were very rough, consisting of loose ice particles and crystals, and rime, that soon melted disclosing the hard interior. The interior consisted of three portions: One of hard, clear ice extending from the apex to about one-fourth the distance to the base; the second containing as many as 12 circular arcs of varying thickness of alternating clear and opaque ice easily visible to the naked eye for one-third the total length, with centers of curvature concentric at the apex; the third portion was of white ice of irregular formation of no definite structure and softer than the previous two.

The method of formation of such irregularly shaped hailstones has been variously explained. One of these is that, from an initial irregularity of the core, the development continued unsymmetrically; the flattened base being kept continually against the droplet bearing air currents, so that streamline flow determined the resultant shape of the added water as it froze. The hypothesis has various difficulties in the present case although it serves for less marked irregularities: (1) The apparently complete absence of any spherical stones would require a uniform condition of asymmetry at the start; (2) streamlining of a partly frozen nucleus into a teardrop design would be most apt to develop a circular or elliptical cross section rather than the polygonal one observed in the trailing apex; (3) the successive layers of clear ice built up around the hailstone would have to be complete, due to excess liquid flowing from face to rear—instead, the portions of arcs found were sharply truncated; and (4) the streamlines about an irregularly shaped object are very seldom circular or concentric with a point on the surface, in contradiction to the condition observed above.

Hann [1] in publishing some photographs of hailstones, which, with the exception that the number of layers were not so numerous, are very similar to those that fell in Washington, briefly remarks that they have the appearance of being formed by the explosion of balls of ice, and other observers believed collisions in the upper air may have shattered the stones, but no further details are given.

The following preliminary computations indicate that the above process is within the realm of possibility.

The rate of heat loss may first be determined from the formula for the steady state conduction of a sphere of radius R_2 with surface temperature fixed at T_2, and whose temperature at a distance R_1 from the center is maintained at T_1.

$$dH=4\pi k\frac{(T_1-T_2)}{R_2-R_1}R_1R_2dt \tag{1}$$

This loss will freeze completely a layer of the nucleus PLM grams where P is the percentage of the liquid nucleus by weight that is frozen, L the latent heat of fusion, M the total mass may be determined from the volume of the shell $4\pi R_1^2$ in area and dR_1 thick.

$$4\pi k(T_1-T_2)\frac{R_1R_2}{R_1-R_2}dt=PLM, \qquad M=4\pi R_1^2dR_1 \tag{2}$$

$$t=\frac{PL}{k(T_1-T_2)R_2}\int(R_2-R_1)R_1dR_1 \tag{3}$$

[1] Hann-Süring: Lehrbuch der Meteorologie, 4 Ed. Leipzig, 1926, p. 720.

In a specific instance, the time required for the nucleus to freeze solid may be determined by substituting the following reasonable values: L is roughly 80 cal/gm; k, the conductivity for solid ice, is 0.0044 cal/cm/sec; T_1 is 0° C. and T_2 may be taken at —15° C. for a dry atmosphere; P as 10 percent; R_1 as 2 cm.; and R_2 as 4 cm.

$$(4)\quad t=\frac{PL}{k(T_1-T_2)R_2}\left[\frac{R_2R_1^2}{2}-\frac{R_1^3}{3}\right]_0^2$$

$$=\frac{0.10\times 80}{0.0044\times 15\times 4}\left[\frac{4\times 2^2}{2}-\frac{2^3}{3}\right]=162 \text{ seconds.}$$

It seems that with the additional knowledge concerning the process of hail formation given by recent authors, notably Schumann,[2] the suggestion of Hann's can be expanded into a complete analysis of the structure of such stones.

In accordance with the usually accepted idea of the origin of hail, the stone started from a rounded nucleus of either compacted, partially melted snow or a large raindrop in which freezing had already begun and formed a network of spicules throughout. Here the latter type may be considered preferable as there would then be no occluded air bubbles. This core could readily grow to a size of one-fourth inch radius, the size of the clear apex portion of the hailstones, through the accretion of supercooled droplets. Assuming the proper proportions between the solids and liquids, the spherical form could be maintained through turbulent air friction and surface tension. Winds, even in excess of the classical terminal velocity of $8m/s$ for raindrops would not disrupt it.

Since the solid crystals would prevent convection, the outer layer would freeze completely first. As long as supercooled droplets were being deposited at a rate sufficient to cover the stone with a film of water, the stone's temperature would remain at 0° C. throughout. Further growth would take place at the surface, as Schumann has described, by the conduction of heat and evaporation of water to the surrounding colder air. The interior would remain in equilibrium because there would be no further transfer of heat across the surface to freeze the liquid remaining within. Because of the slight lowering of the freezing point of water with increasing pressure, the freezing point within the center would be slightly lower than on the free surface. Layer upon layer of clear and opaque ice could be added until the diameter of the stone reached the required 1½ to 2 inch. Should the hail be carried to such a height that all external liquids would be frozen, a temperature of below 0° C. could eventually penetrate to the nucleus.[3] As the nucleus began to freeze, the change of state would produce a change in volume capable of creating a tremendous internal pressure. This could easily exceed the breaking strength of the ice shell and the hailstone would explode like an aerial bomb, shattering into polygonal pyramids with spherical bases.

This time is the minimum amount since the conditions for the steady state demanded for equation 1 were not observed in equation 3. As the pressure within the hailstone may reach the bursting point long before the freezing is completed even 162 seconds may be unnecessarily long.

Whether the hailstone will explode or merely expand is difficult to determine since it is known that above −9° C. ice is sufficiently plastic to flow and offset the internal pressure developed, and also since accurate measurements of the tensile strength, modulus of elasticity, and compressibility of ice are extremely variable and difficult to make at the lower temperatures.[4]

Since water expands one-tenth its volume on freezing, the nucleus considered here will change its volume by one one-hundredth. Assuming no plastic flow and negligible compression, the outer radius will be increased by an amount

$$(5)\quad dR_2=\frac{\frac{4}{3}\pi R^3{}_1}{4\pi R^2{}_2}1/100=\frac{8}{300\times 16}=0.00166 \text{ cm.}$$

Let us consider the stress developed in the outer layers to be equal to that required to produce a proportional extension in a uniform bar of solid ice. Then Hooke's law gives

$$(6)\quad s=\left(\frac{dR_2}{R_2}\right)E=\frac{0.00166}{4}\times 3\times 10^7 g/cm^2$$

$$=1.24\times 10^4 g/cm^2=1.22\times 10^7 \text{ dynes/cm}^2$$

where E is Young's modulus and is an approximate value.[5]

Since the tensile strength of ice is from 1 to 10 times 10^3g/cm^2, failure would readily occur.

If any "bombs" were capable of withstanding the internal forces, it is hardly likely they could survive the impact with the ground because of their unstable condition. In the cases where the nuclear liquid was small, the parts might not be completely severed and would refreeze in a malformed shape upon the release of pressure. On extremely mild occasions, or where air bubbles were occluded, the expansion would merely produce the radial structure often seen.[6]

In the remaining time of descent, ice and rime could be added over the fragments. Portions of the nucleus would become completely frozen and hard, in contrast to the usual condition of intact spherical stones which have soft nuclei indicative of incomplete freezing.

If it were possible for a raindrop to remain liquid at the center while a frozen layer formed over the surface, or if the crystal-liquid mixture were not firmly frozen to the shell, the resulting fracture might produce the lens or saucer shaped hail occasionally seen.

The above discussion of the formation of irregularly shaped pyramidal hailstones such as fell in Washington on April 29, 1938, leads to the following conclusions: Due to certain internal structural features of the stones, the previously held hypothesis that such forms developed from the maintenance of an initial irregularity of the nucleus has been discarded. A suggestion due to Hann that the stones arose through the bursting of a much larger spherical stone has been found to explain the structure and also to satisfy certain mathematical requirements and is therefore advanced as being more valid.

Finally I should like to thank Dr. C. F. Brooks and Dr. A. F. Spilhaus for their interest and criticism of this paper while it was still in a formative state and for suggesting several important additions.

[2] T. E. W. Schumann: The Theory of Hail Formation. *Quar. Jour. R. M. S.* v. 64, p. 3, Jan., 1938.

[3] Hann. (p. 722) states that the temperature of hailstones measured immediately after their fall is often much below zero and can reach from −5 to −15° C.

[4] H. T. Barnes: *Ice Engineering*, Renouf Publ. Co., Montreal 1928. See pp. 21–59 for a consideration of the properties of ice.

[5] Ewing, Crary, and Thorne in an article published in *Physics* 8: 1–9, June 1934 make the following statement: "The values of Young's modulus and Poisson's ratio for ice are found to be 9.17×10^{10} dynes/cm^2 and 0.365, respectively, in the range −5° to −15° C.".

[6] F. W. Very: The Hailstorm of May 20, 1892, *Amer. Met. Jour.*, pp. 263–273, Oct. 1893. This author gives a description and cuts of the internal structure of hailstones whose nuclei he concludes froze from the surface inward.

NOTE ON THE HAILSTONES OF AUGUST 9, 1938, AT WILLIAMSTOWN

The following description of hailstones that fell in Williamstown, Mass, on August 9, 1938, has been received from Prof. Willis I. Milham who gathered the reports from several reliable observers:

Four forms (of hailstones) are mentioned—a perfect sphere; a flattened sphere; entirely irregular; pyramidal with a curved base. The commonest seems to have been the pyramidal form and many comment that the pyramids were long and sharp. The flattened sphere comes next. Some remark that two or three stones were often welded together long before they reached the surface and fell as a solid mass. They were laminated, and one observer remarked that they looked like mothballs surrounded by clear ice. There was almost no thunder and lightning in Williamstown. In Pownal, Vt., about 5 miles away, where the storm was even more destructive, there was more lightning and thunder.

THE STRUCTURE OF HAILSTONES

R. P. Johnson, of the Research Laboratory, General Electric Co., Schenectady, N. Y., in an account of the broken hailstones, published in Nature, vol. 142, page 172, July 23, 1938, states that the shapes of these stones and their stratification showed plainly that they were fragments of larger spherical stones about 30 mm in diameter, in which clear and cloudy layers had alternated about every 2 mm. It was concluded that where fracture took place it was at a high level, for the pieces, which ranged up to 15 mm in size, appeared to have terminal velocities suited to their sizes. They did not break on striking the pavement. The absence of layers of clear and cloudy ice built on to each fragment seemed to prove that the stones were fractured below the region where they were formed. The remarkable fact that all the stones were broken at the place of observation, while 2 miles away only complete stones fell, suggested to J. Schremp (another of the research engineers of the General Electric Co.) that the shattering was caused by a pressure wave that was set up by a bolt of lightning that passed near to them as they fell.

RAINS IN KANSAS

By ANDREW D. ROBB

[Weather Bureau, Topeka, Kans., March 1938]

The interest Kansas has in rains is due at times to the lack of rain, at times to the overabundance of rain, and at other times it is due to those million-dollar rains that come to the State.

The average annual amount of rainfall varies from about 43 inches in the southeastern part of Kansas to approximately 16 inches in the central counties of the western third. The amounts of rainfall, however, are only a part of the story, for the number and magnitude of the rains are important factors for consideration in many enterprises. For example, rainfall in the counties of the central third of western Kansas is only 37 percent of that of southeastern Kansas while the average number of rains is nearly 60 percent. As data on monthly and annual amounts of precipitation are readily available in the monthly and annual Climatological Data for Kansas the discussion here will deal mostly with the number and magnitude of rains that fall over Kansas.

The term "rains" as used here means the amounts of water measured at the observation, whether from rain, snow, sleet, or hail. Each of the three Weather Bureau divisions of the State were subdivided into three districts. Three cooperative stations in each district were selected, considering geographical distribution and continuity of record. The time covered is the 40 years from January 1896 to December 1935. The limits of the magnitudes chosen for this study are as follows: 0.01 to 0.25 inch; 0.26 to 0.50 inch; 0.51 to 0.75 inch; 0.76 to 1.00 inch; 1.01 to 1.50 inches; 1.51 to 2.00 inches; 2.01 to 3.00 inches; 3.01 inches and over.

The number of rains of these various magnitudes were counted by months during this 40-year period for each of the three stations of the nine districts. The rains of like magnitudes of the three stations of each district were then averaged together to determine the average for the district. The results are summarized in tables 1 to 9.

AVERAGE NUMBER OF DAYS WITH RAIN—40 YEARS, 1896–1935

TABLE 1.—*Northwest section—Dresden, Colby, Atwood, St. Francis*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	83	123	142	166	209	202	160	152	115	100	79	103	1,634
0.26-0.50	9	21	24	50	58	57	47	57	31	30	20	14	418
0.51-0.75	1	6	9	23	26	32	20	31	18	13	9	6	194
0.76-1.00	-----	1	3	16	13	21	16	16	14	6	4	2	112
1.01-1.50	1	1	4	11	15	16	14	13	9	6	1	2	93
1.51-2.00	0	0	1	5	6	6	6	7	4	2	1	-----	38
2.01-3.00	0	0	1	2	1	2	4	3	2	2	1	0	18
3.01 and over	0	0	0	0	-----	-----	3	0	1	2	0	0	6
Total	94	152	184	273	328	336	270	279	194	161	115	127	2,513

TABLE 2.—*North-Central section—Phillipsburg, Hanover, Beloit, Burr Oak, Alton*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	97	116	140	175	209	211	163	163	152	120	103	104	1,753
0.26-0.50	16	28	32	57	72	69	50	52	43	44	28	18	509
0.51-0.75	7	8	13	28	36	44	27	32	22	13	12	7	249
0.76-1.00	1	5	4	16	26	21	14	18	14	11	5	5	140
1.01-1.50	0	1	4	12	18	24	17	20	12	11	5	2	126
1.51 2.00	0	1	1	3	8	10	11	9	9	6	3	1	62
2.01-3.00	0	-----	-----	2	3	4	7	6	4	3	1	0	30
3.01 and over	0	0	0	1	2	1	1	2	2	1	-----	0	10
Total	121	159	194	294	374	384	290	302	258	209	157	137	2,879

TABLE 3.—*Northeast section—Atchison, Manhattan, Frankfort, Centralia, Oketo*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	131	131	153	168	197	160	137	149	129	135	105	114	1,709
0.26-0.50	24	37	41	63	73	65	55	51	63	42	35	34	583
0.51-0.75	7	16	19	35	44	49	32	33	37	27	16	10	325
0.76-1.00	3	5	7	20	31	27	21	21	25	18	9	3	190
1.01-1.50	2	5	10	17	21	28	25	27	24	14	11	1	185
1.51-2.00	0	2	3	6	14	13	8	10	12	4	5	1	78
2.01-3.00	0	0	2	3	10	10	7	11	10	2	2	1	58
3.01 and over	0	0	-----	-----	1	3	3	3	3	0	1	0	14
Total	167	196	235	312	391	355	288	305	303	242	184	164	3,142

TABLE 4.—*West-Central section—Ness City, Gove, Wallace, Quinter, Sharon Springs*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	58	84	91	128	150	162	138	134	101	82	75	66	1,269
0.26-0.50	7	22	19	49	51	61	51	48	34	25	16	16	399
0.51-0.75	1	5	7	20	29	30	27	24	15	10	7	5	180
0.76-1.00	-----	3	3	10	16	15	17	16	8	6	5	4	103
1.01-1.50	1	1	3	9	17	16	18	12	8	8	3	2	98
1.51-2.00	0	-----	1	3	6	6	8	7	6	2	1	1	41
2.01-3.00	0	0	0	3	1	1	2	2	3	1	0	1	14
3.01 and over	0	0	0	-----	1	3	-----	-----	2	0	0	0	6
Total	67	115	124	222	271	294	261	243	177	134	107	95	2,104

TABLE 5.—*Central—Salina, McPherson, Hays*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	100	118	131	170	209	186	151	145	142	120	98	109	1,679
0.26-0.50	19	29	27	57	73	62	51	49	42	39	24	24	496
0.51-0.75	7	11	14	30	35	36	24	29	23	18	15	10	252
0.76-1.00	3	6	8	18	25	28	20	18	14	15	9	3	167
1.01-1.50	1	4	5	13	20	30	19	22	19	12	7	3	155
1.51-2.00	0	1	2	4	6	12	8	7	6	6	3	-----	55
2.01-3.00	0	0	0	3	7	9	4	6	5	3	1	-----	38
3.01 and over	0	0	0	-----	2	3	2	2	2	0	0	0	11
Total	130	169	187	295	377	366	279	278	253	213	157	149	2,853

TABLE 6.—*East-Central section—Lawrence, Emporia, Paola*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	124	119	137	188	207	168	138	151	138	136	102	123	1,731
0.26-0.50	25	37	42	71	74	67	55	50	58	49	34	35	597
0.51-0.75	10	16	25	36	47	40	31	32	27	31	18	14	327
0.76-1.00	6	9	15	20	32	25	25	17	26	14	9	6	204
1.01-1.50	5	5	10	18	27	28	21	32	28	14	11	5	204
1.51-2.00	1	1	6	6	13	12	10	10	13	8	5	1	86
2.01-3.00	0	1	2	5	9	9	10	12	10	6	-----	0	64
3.01 and over	-----	0	-----	0	4	5	2	2	3	2	2	-----	20
Total	171	188	233	344	413	354	292	306	303	260	181	184	3,233

TABLE 7.—*Southwest section—Ashland, Garden City, Richfield*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	64	84	98	125	160	144	139	119	101	94	83	75	1,286
0.26-0.50	9	25	24	46	48	50	41	47	29	23	20	16	378
0.51-0.75	5	6	10	29	26	30	32	23	21	13	8	6	209
0.76-1.00	1	4	4	10	15	19	15	14	9	9	6	4	110
1.01-1.50	-----	2	3	11	12	16	18	14	12	10	6	3	107
1.51-2.00	0	1	1	3	6	8	5	5	5	4	1	1	40
2.01-3.00	0	-----	-----	4	4	4	4	3	3	1	1	-----	24
3.01 and over	0	-----	0	1	1	1	1	1	1	1	0	0	7
Total	79	122	140	209	272	272	255	226	181	155	125	105	2,161

TABLE 8.—*South-central section—Hutchinson, Medicine Lodge, Macksville, Hudson*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	91	106	117	145	198	177	139	148	130	113	89	91	1,544
0.26-0.50	19	27	37	53	58	55	49	44	52	41	27	23	485
0.51-0.75	5	6	12	31	35	35	25	26	26	22	13	9	245
0.76-1.00	2	4	5	16	25	23	13	13	15	10	8	3	137
1.01-1.50	2	4	6	9	21	24	21	21	14	11	9	3	145
1.51-2.00	0	4	2	4	11	12	6	7	8	5	4	1	61
2.01-3.00	0	1		3	6	6	5	5	5	2	1	0	34
3.01 and over	0	0	1	1	2	3	2	3	1	1	0		14
Total	119	149	180	262	356	335	260	267	251	205	151	130	2,665

TABLE 9.—*Southeast section—Eureka, Fort Scott, Independence*

Magnitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0.01-0.25	151	135	188	198	223	159	147	163	150	143	125	128	1,910
0.26-0.50	33	40	51	71	79	68	56	52	49	48	35	35	617
0.51-0.75	15	18	22	37	47	39	25	30	33	29	22	14	331
0.76-1.00	6	7	19	29	29	24	31	23	23	19	13	9	232
1.01-1.50	7	7	16	26	31	31	22	15	24	18	14	5	211
1.51-2.00	1	3	2	5	14	10	13	10	12	11	7	5	93
2.01-3.00	1	1	4	5	10	13	8	7	8	6	5	1	69
3.01 and over	0	-----	0	1	2	5	3	1	5	2	-----	0	19
Total	214	211	302	372	430	349	305	301	314	276	221	197	3,482

Inasmuch as it is impracticable to give a detailed analysis of the preceding tables, only a few points of interest will be discussed.

Southeast Kansas, as shown by the data in table 9, has had 3,482 rains during the 40-year epoch, about 87 per year. The fewest number of rains occurred in the west-central section, table 4, where they had only 2,104 in the 40 years, an average of about 52 per year.

Rains of the smallest magnitude, 0.01 to 0.25 inch, are course the more numerous, being a little more than half of all those recorded in each district. Rains of the second magnitude, 0.26–0.50 inch, comprise about one-fifth; those of the third magnitude, 0.51 to 0.75 inch, about one-tenth; and those of the fourth magnitude, 0.76 to 1 inch, about one-twentieth of total number. Rains of one inch or less comprise about 90 percent of the total number.

The months of November, December, and January have the least number of rains; May and June in the eastern and western portions, respectively, have the greatest number. In all parts of the State there is a marked falling off in the number of small rains in the summer months and a considerable increase in the number of rains of greater amounts. July, especially in the eastern half of the State, has had fewer rains of all magnitudes than either June or August.

The question of how much water falls in the rains of the several magnitudes is of interest. All of the rains during this 40-year period at Columbus, Kans., where O. E. Skinner has kept the entire record, were tabulated and totaled by magnitudes. The average amount of precipitation for each magnitude was computed and the percentages of the number of rains and amounts of precipitation for each magnitude were determined and are given in table 10.

TABLE 10.—*Summary of rains at Columbus, Kans., 1896–1935*

Magnitude	Number of rains	Amount of precipitation	Average amount	Percent of total rains	Percent of total precipitation
Inches		*Inches*	*Inches*		
0.01-0.25	2,008	166.87	0.08	53	10
0.26-0.50	643	239.79	.37	17	14
0.51-0.75	403	251.41	.62	11	15
0.76-1.00	224	195.98	.87	6	12
1.01-1.50	226	324.57	1.23	7	19
1.51-2.00	112	191.92	1.69	3	11
2.01-3.00	86	211.57	2.48	2	12
3.01 and over	28	112.31	3.86	1	7
	3,770	1,693.22	.45	100	100

During this 40-year period Mr. Skinner has measured 3,770 rains totaling 1,693.22 inches, or about 141 feet, of water. The 2,008 rains of the smallest magnitude were 53 percent of all the rains, but yielded only 10 percent of the total precipitation. On the other hand the falls of 3.01 inches and over, comprised only 1 percent of all rains, but they accounted for 17 percent of the total precipitation. About two-thirds as much rain fell in these 28 very heavy rains as in the 2,008 rains of the smallest magnitude.

When the magnitudes of rain are arranged by 1-inch groups, those of the first inch constitute 87 percent of all rains and 51 percent of all the precipitation. The percentages for those between 1.01 and 2.00 inches are 10 and 30; between 2.01 and 3.00 inches 2 and 12; and over 3 inches 1 and 7 percent, respectively.

The average amount of rainfall for each magnitude varies from 0.08 inch for the smallest to 2.86 inches for the heaviest, with an average of 0.45 inch for all rains. A close approximation to the amount of moisture received

in the rains of the various magnitudes may be determined by multiplying the averages of table 10 by the average number of rains of each magnitude in each district.

The frequency of heavy rainfall and the number of droughts were also found for this 40-year period. The limits selected were the frequency of rains of 2.00 inches and over, and the number of days between rains of 0.25 inch during the crop growing season.

The 12 stations named in table 11, cover, in a general way, most of the State of Kansas. The table gives the number of rains of 2.00 inches or more. The first column shows the number of times a rain of 2.00 inches or more was followed on the succeeding day by a similar rain. In most cases these were not separate rains, but rather continuations of the same rain. At Manhattan 2.00 inches or more fell on succeeding days 3 times. At Coldwater the shortest interval between rains of 2.00 inches or more is 18 days; and at Dresden only 2 rains of 2.00 inches or more have been recorded within 20 days of each other, and they came on succeeding days. Heavy rains occur much more frequently in the eastern than in the western part of Kansas.

TABLE 11.—*Number of occurrences of rains of 2 inches or more at various intervals, 1896–1935*

Station	Number of days between rains of 2 inches or more																				
	0[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Columbus	..	1	..	2	..	1	..	1	..	1	..	1	1	1	1	..	..	3	1	1	..
Atchison	1	1	..	1	2	..	..	..	2	..	1	..	..	..	1	..	..	..	..	1	..
Eureka	2	..	2	1	..	1	2	1	1	..	1	..	..	..	..	..	1	1	..	1	..
Manhattan	3	..	..	..	1	1	..	2	1	..	..	..	..	..	2	..	1	..	2	..	..
McPherson	2	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	1
Burr Oak	2	..	..	..	..	..	..	..	..	..	1	..	1	..	..	..	..	..	1	..	..
Hays	2	..	..	1	..	..	..	1	..	..	..	..	1	..	..	..	..	..	..	..	1
Coldwater	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
Dresden	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Liberal	1	..	..	..	..	..	..	..	..	..	1	..	..	..	1	..	..	..	1	..	..
Garden City	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..
Sharon Springs	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..

[1] Rains of 2 inches or more on consecutive days.

Using the same stations and the same period of time, the number of periods of 30 days or more without a rain of 0.25 inch or more in 24 hours during the growing season, April 1 to September 30, were counted. The results are shown in figure 1. Columbus reports the fewest, having had only 15 such occurrences during the 40-years. The number of these 30-day, or longer, dry periods increases greatly to the westward across the State; Richfield, in the southwestern corner, has had 76 in the 40-years, five times as many as in the southeastern counties.

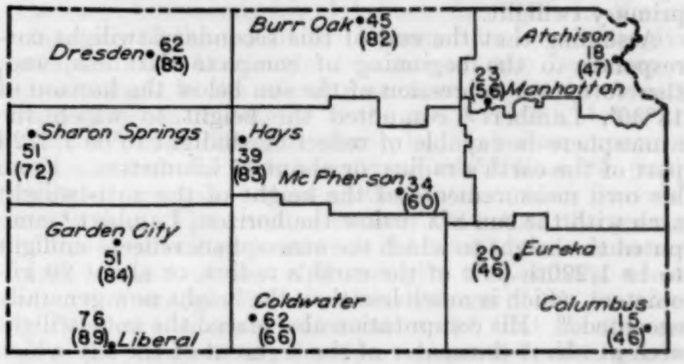


FIGURE 1.—The number of periods of 30 days, or more, without a rain of 0.25 inch, or more, in 24 hours for the past 40 years (1896–1935), March 1 to September 30 each year. Numbers in parentheses are greatest number of days between rains of 0.25 inch, or more.

On an average the eastern third of Kansas has only one of these dry periods during a growing season every two years, the middle third one a year, and the western third three in two years.

The numbers in parentheses in figure 1 show the greatest number of days, during the growing season, between rains of 0.25 inch or more. On this basis the longest drought in the eastern third was approximately 49 days; in the middle third 62 days; and in the western third 82 days; with 89 days, May 5–July 31, 1933, being the longest on record for a particular station.

THE DURATION AND INTENSITY OF TWILIGHT

By HERBERT H. KIMBALL

[Reprinted from MON. WEATH. REV., 44: 614-620, 1916]

INTRODUCTION

Officials of the Weather Bureau frequently receive requests for information relative to the intensity of the light at some specified time, usually during the hours of twilight. Twilight illumination is, of course, markedly influenced by the state of the sky as regards clouds, haze, smoke, etc. Aside from this it is dependent on the angular depression of the sun below the horizon and the position and phase of the moon.

THE DURATION OF TWILIGHT

One of the earliest accessible treatises on twilight is by Johann Heinrich Lambert,[1] who states that ancient astronomers had found for the beginning of complete darkness at night and its ending in the morning a depression of the sun below the horizon of from 18° to 19°.[2] According to Kaemtz [3] they also gave a s a rule that at this time stars of the sixth magnitude should be visible near the zenith.

Kaemtz [4] also describes the anti-twilight, which includes what many observers have called the anticrepuscular or anti-twilight arch, below which the sky is of an ashy or a deep blue color, depending on its clearness, and above which it takes on a reddish tinge. Under favorable atmospheric conditions, and specially in arid regions at a considerable elevation above sea level, this arch may be observed to rise in the east soon after sunset. Lambert,[5] at Augsburg, Germany, on November 19, 1759, made measurements from which he computed that it passed his zenith when the sun was 5°50′ lower than at its apparent setting; or, allowing 33′ for atmospheric refraction, when the depression of the sun below the horizon was 6°23′. Bravais,[6] from observations made on the summit of the Faulhorn, Switzerland, at an elevation of 2,685 meters above sea level, found it to pass his zenith when the sun was 6°9′ below the horizon, and to reach the horizon when the depression of the sun was 17°30′.

On the assumption that the anti-twilight arch represents the limit of direct illumination of the atmosphere

[1] Lambert's Photometrie (1760), Zweites Heft; Theil III, IV, and V, pp. 96-112. (Ostwald's Klassiker der exakten Wissenschaften. Nr. 32. Leipzig, 1892.)
[2] For a bibliography summarizing these determinations see Houzeau, J. C., Vademecum de l'astronome. Bruxelles, 1882, p. 313-316.
[3] Meteorology, by L. F. Kaemtz. Notes by Ch. Martins. Translated by C. V. Walker, London, 1845, p. 410.

[4] Op. cit., p. 408.
[5] Op. cit., p. 104.
[6] Bravais, M. A. Observations sur les phénoménes crépusculaires. Annuaire Météorologique de la France pour 1850, 2me Année. p.185-218. (See Note additionnelle, p. 215.)

by the sun, Lambert [7] shows that a depression of the sun below the horizon of 18°30′ at the end of twilight gives 1/89th part of the earth's radius, or about 70 kilometers, as the height to which the atmosphere is capable of reflecting sunlight. This seemed to him to be too high, and he therefore supposed twilight to be divided into two periods, a primary twilight, and a secondary twilight. The primary twilight he attributed to light reflected from portions of the atmosphere directly illuminated by the sun. Secondary twilight he attributed to reflection of light from portions of the atmosphere illuminated by the primary twilight.

Assuming that the end of this secondary twilight corresponds to the beginning of complete darkness, and, therefore, to a depression of the sun below the horizon of 18°30′, Lambert [8] computed the height to which the atmosphere is capable of reflecting sunlight to be 1/372d part of the earth's radius, or about 17 kilometers. From his own measurements of the height of the anti-twilight arch with the sun 8°3′ below the horizon, Lambert [9] computed the height to which the atmosphere reflects sunlight to be 1/220th part of the earth's radius, or about 29 kilometers, which is much less than the height now generally accepted.[10] His computation also placed the anti-twilight arch at about the center of the segment of the sky which he supposed to be illuminated by secondary reflection, and he therefore concluded that the light in one half this segment is so feeble as to be obscured by the light of the fixed stars.

This conclusion of Lambert's found favor with Biot,[11] but was rejected by Grunert,[12] who shows that Lambert's observations give increasingly higher values for the height of the upper limit of the reflecting atmosphere with increasing depression of the sun below the horizon.

Kaemtz [13] also states that "This segment [the deep blue of the anti-twilight] is due to the shadow of the earth projected on the sky," and a note by Martins [14] defines the *second twilight* to be the feeble white light that under favorable conditions is sometimes observed from high mountains after the anti-twilight arch has set, and which has been observed to continue until the sun was 26° below the horizon. It is also stated that this second twilight has not been observed at low-level stations.

Láska [15] and also Exner [16] ignore the secondary twilight of Lambert. Following Bezold,[17] however, Exner distinguishes between a "first" and a "second" twilight, the "first" twilight terminating in the evening with the disappearance of the first purple light, which is often a prominent feature of twilight phenomena. According to Bezold's observations, the anti-twilight arch can not be observed to pass the zenith, but can sometimes be seen to reappear in the western sky about 30° past the zenith. Its final disappearance marks the end of astronomical twilight.

Tables of the duration of astronomical twilight.—In early numbers of the Berliner Astronomisches Jahrbuch [18] will be found tables giving the duration of astronomical twilight for each day in the year. From the explanation of the use of the Ephemeriden in the Jahrbuch for 1776, pages 20–21, it appears that sunrise or sunset is considered to be that instant when the center of the sun coincides with the true horizon, disregarding the effect of atmospheric refraction; and as astronomical twilight begins in the morning and ends in the evening when the true position of the sun's center is 18° below the horizon. The interval between the time of sunrise or sunset thus computed and the time the sun is 18° below the horizon is the duration of astronomical twilight given.

In the Annuaire Astronomique de l'Observatoire Royal de Belgique [19] is published a table giving the duration of astronomical twilight for each fifth degree of latitude at the time of the equinoxes and of the summer and winter solstices that is in accord with the above.

In the Comptes Rendus for 1860, 50:81, M. F. Petit presents, for latitudes 48° and 49° N., some preliminary computations of the duration of twilight, or the interval between the time the center of the sun appears to be on the horizon, allowing 33′ 30″ for atmospheric refraction, and the time the true position of the sun's center is 18° below the horizon. In the Comptes Rendus for 1860, 51:486–489, he published a table giving the duration of twilight for each degree of solar declination from −24° to +24° and for each degree of latitude from 0° to 70°.

This table appears to be the basis for most of the tables giving the duration of astronomical twilight since published. Thus, in the "Annuaire Astronomique et Météorologique pour 1893 par Camille Flammarion" is a table giving the duration of astronomical twilight for each fifth degree latitude and for 15-day intervals, beginning with January 1. No authority is given, but it appears to be in accord with Petit's table, and might, indeed, have been obtained by interpolation in it for the solar declination on the days for which data is given.

Likewise, Láska [20] published a table giving the duration of astronomical twilight that is attributed to the Annuaire for 1905. His table states in the heading that the data refer to the first day of the respective months; but they seem to have been copied directly from the Annuaire, taking for the first day of the respective months the data for the date given in the table that falls nearest the first, although in some cases this may have been as early as the 26th of the preceding month. In a few cases only does it appear that an attempt has been made to obtain correct data by interpolation. This table of Láska's has been copied by Exner.[21]

From the above brief review of the literature it is apparent that the uniform practice in the computation of tables of the duration of astronomical twilight has been to regard the time of its beginning in the morning, or its ending in the evening, as that instant when the true position of the center of the sun is 18° below the horizon; although the earlier observers, as has already been shown, gave a slightly greater depression of the sun at the beginning or end of complete darkness, and later observers have generally found a somewhat less depression, namely, from 16° to 18°.[22] The tables of duration of twilight, however, show variations due to differences with respect to the position of the sun at its rising and setting. The older German writers, as already shown, considered the sun to rise or set when its center coincided with the true horizon, disregarding atmospheric refraction; modern French and Belgians consider sunrise or sunset to be that instant when

[7] Op. cit., p. 102.
[8] Op. cit., p. 102.
[9] Op. cit., p. 106.
[10] See *Heim, Albert*, Luft-Farben. Hofer & Co. Zurich, 1912. p. 68.
[11] *Biot, J. B.* Traité élémentaire d'Astronomie physique. 3d ed. Paris, 1841. Vol. 1, p. 309–323.
[12] *Grunert, Johann August.* Beiträge zur meteorologischen Optik. Leipzig, 1848. Erster Theil, Erstes Heft, p. 194–264.
[13] Op. cit., p. 408.
[14] *Kaemtz*, op. cit., p. 409; see also p. 499, note "G."
[15] Láska, Prof. Dr. W. Lehrbuch der Astronomie und der mathematischen Geographie. II. Auflage. I. Teil:Spharische Astronomie. Bremerhaven und Leipzig, 1906, p. 74–78. (Kleyers Encyklopädie der gesamten mathematischen, technischen und exakten Naturwissenschaften.)
[16] Pernter, J. M., & Exner, Felix M. Meteorologische Optik. Wien und Leipzig, 1910. p. 739–799.
[17] See Abbe's translation of Bezold's description of twilight phenomena, with Exner's discussion, p. 17–23 of this separate.
[18] See the "Ephemeriden" in the Jahrbücher for 1776–1829.
[19] See, for example, the Annuaire for 1907, p. 193.
[20] Op. cit., p. 77.
[21] *Pernter & Exner*, op. cit., p. 743.
[22] See *Láska*, op. cit., p. 74; *Grunert*, op. cit., p. 221; *Pernter & Exner*, op. cit., p. 743, 766, 767; *Schmidt, J. F. Julius.* Ueber die Dämmerung. Astronomische Nachrichten No. 1495–1496, Altona, 1865. 36. col. 97–116.

the *center* of the sun *appears* to be on the true horizon; while modern English and German writers consider it to be the instant when the *upper limb* of the sun appears to be on the horizon. These two latter, therefore, apply a correction for atmospheric refraction to the computed position of the sun at sunrise or sunset.

Table 1 of the present paper gives the length of the period between the time when the upper limb of the sun appears to coincide with the true horizon and the time the true position of its center is 18° below the horizon. Allowing 16′ for the sun's semidiameter, and 34′ for atmospheric refraction, the sun is then only 17° 10′ lower than at the time of sunrise or sunset.

The computations may be made from the equation

$$h=\frac{\sin a-\sin\phi\sin\delta}{\cos\phi\cos\delta}$$

where h is the sun's hour angle from the meridian, a is the sun's altitude, considered minus below the horizon, δ is the solar declination, and ϕ is the latitude of the place of observation.

TABLE 1.—*Duration of astronomical twilight.* (*Interval between sunrise or sunset and the time when the true position of the sun's center is 18° below the horizon*)

Date	North latitude														
	0°	10°	20°	25°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°
	h. m	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*	*h. m*
Jan. 1	1 14	1 15	1 18	1 21	1 26	1 28	1 29	1 31	1 34	1 37	1 41	1 45	1 49	1 53	1 59
11	1 14	1 14	1 18	1 21	1 25	1 27	1 29	1 31	1 33	1 36	1 39	1 43	1 47	1 52	1 57
21	1 13	1 13	1 17	1 20	1 23	1 25	1 28	1 30	1 32	1 34	1 38	1 41	1 45	1 49	1 54
Feb. 1	1 12	1 12	1 15	1 18	1 22	1 24	1 26	1 28	1 30	1 33	1 36	1 39	1 43	1 47	1 52
11	1 11	1 12	1 14	1 17	1 21	1 23	1 25	1 27	1 29	1 32	1 34	1 37	1 41	1 45	1 49
21	1 10	1 11	1 13	1 16	1 20	1 22	1 24	1 26	1 28	1 31	1 33	1 36	1 40	1 44	1 48
Mar. 1	1 10	1 11	1 13	1 16	1 20	1 21	1 23	1 25	1 28	1 30	1 33	1 36	1 39	1 43	1 48
11	1 09	1 10	1 13	1 16	1 19	1 21	1 23	1 25	1 28	1 30	1 33	1 36	1 39	1 43	1 48
21	1 09	1 10	1 13	1 16	1 20	1 22	1 24	1 26	1 29	1 31	1 34	1 37	1 41	1 45	1 50
Apr. 1	1 09	1 11	1 14	1 17	1 21	1 23	1 25	1 27	1 30	1 33	1 36	1 40	1 44	1 49	1 54
11	1 10	1 11	1 15	1 18	1 22	1 24	1 27	1 30	1 33	1 36	1 39	1 43	1 48	1 54	2 00
21	1 11	1 12	1 16	1 20	1 24	1 27	1 29	1 32	1 36	1 39	1 43	1 48	1 54	2 01	2 08
May 1	1 12	1 13	1 18	1 22	1 27	1 30	1 33	1 36	1 39	1 43	1 48	1 54	2 01	2 10	2 20
11	1 13	1 14	1 19	1 24	1 30	1 33	1 36	1 40	1 43	1 48	1 54	2 01	2 10	2 20	2 35
21	1 13	1 15	1 21	1 26	1 32	1 36	1 39	1 43	1 48	1 54	2 01	2 10	2 20	2 35	2 58
June 1	1 14	1 16	1 23	1 28	1 35	1 38	1 41	1 46	1 52	1 59	2 07	2 18	2 31	2 54	----
11	1 15	1 17	1 24	1 29	1 36	1 40	1 44	1 49	1 55	2 02	2 12	2 23	2 40	3 11	----
21	1 15	1 18	1 24	1 29	1 37	1 41	1 45	1 50	1 56	2 03	2 13	2 25	2 44	3 19	----
July 1	1 15	1 17	1 24	1 29	1 36	1 40	1 44	1 49	1 55	2 02	2 12	2 23	2 40	3 10	----
11	1 14	1 16	1 23	1 28	1 35	1 38	1 41	1 46	1 52	1 59	2 07	2 18	2 31	2 54	----
21	1 13	1 15	1 21	1 26	1 32	1 36	1 39	1 43	1 48	1 54	2 01	2 10	2 21	2 36	3 00
Aug. 1	1 13	1 14	1 19	1 24	1 30	1 33	1 36	1 40	1 44	1 48	1 54	2 02	2 10	2 20	2 35
11	1 12	1 13	1 18	1 22	1 27	1 30	1 33	1 36	1 39	1 43	1 48	1 54	2 01	2 10	2 20
21	1 11	1 12	1 16	1 20	1 24	1 27	1 30	1 33	1 36	1 39	1 43	1 48	1 54	2 01	2 09
Sept. 1	1 10	1 11	1 14	1 18	1 22	1 24	1 27	1 30	1 33	1 36	1 39	1 43	1 48	1 53	2 00
11	1 09	1 11	1 13	1 17	1 21	1 23	1 25	1 27	1 30	1 33	1 36	1 39	1 44	1 49	1 54
21	1 09	1 10	1 13	1 16	1 20	1 22	1 24	1 26	1 29	1 31	1 34	1 37	1 41	1 45	1 50
Oct. 1	1 09	1 10	1 13	1 16	1 19	1 21	1 23	1 25	1 28	1 30	1 33	1 36	1 39	1 43	1 48
11	1 10	1 11	1 13	1 16	1 19	1 21	1 23	1 25	1 28	1 30	1 33	1 36	1 39	1 43	1 48
21	1 10	1 11	1 13	1 16	1 20	1 22	1 24	1 26	1 28	1 31	1 33	1 36	1 40	1 44	1 48
Nov. 1	1 11	1 12	1 14	1 17	1 21	1 23	1 25	1 27	1 29	1 32	1 34	1 38	1 41	1 46	1 49
11	1 12	1 12	1 16	1 18	1 22	1 24	1 26	1 28	1 30	1 33	1 36	1 40	1 43	1 47	1 52
21	1 13	1 13	1 17	1 20	1 24	1 26	1 28	1 30	1 32	1 35	1 38	1 42	1 46	1 49	1 55
Dec. 1	1 14	1 14	1 18	1 21	1 25	1 27	1 29	1 31	1 33	1 36	1 40	1 44	1 47	1 52	1 57
11	1 14	1 15	1 18	1 22	1 26	1 28	1 30	1 32	1 34	1 37	1 41	1 45	1 49	1 53	1 59
21	1 15	1 16	1 19	1 22	1 26	1 28	1 30	1 32	1 35	1 38	1 41	1 45	1 49	1 54	1 59

The solar declinations employed are those given in the American Ephemeris and Nautical Almanac, 1899, pp. 377–384, Solar Ephemeris for Washington, which are very close average values.[23]

The computations have been simplified by the use of Ball's Altitude Tables,[24] from which the value of h has been determined for true altitudes of the sun of $-50'$ and $-18°$. The difference between these two values is the duration of astronomical twilight. It is, therefore, from 1 to 2 minutes less than that given in Petit's table and from 3 to 7 minutes less than that given in the Berliner Astronomisches Jahrbuch and in the Annuaire Astronomique de Belgique above quoted, the magnitude of the differences increasing with the latitude.

Tables of the duration of civil twilight.—Definitions of civil twilight.—There is a lack of definiteness and of uniformity in the definitions of *civil twilight*. Thus the Berliner Astronomisches Jahrbuch for 1776, in the explanation of the use of the Ephemeriden, page 22, gives what it calls Lambert's definition of the beginning of civil twilight in the morning or its ending in the evening, namely, when the center of the sun is 6° 23¼′ below the horizon,[25] or 5° 50′ lower than when its center appears to coincide with the true horizon, at which time the [anti-] twilight arch passes through the zenith. Also, Bravais [26] states that "The results obtained show that the passage of the [anti-twilight] curve at the zenith, the commencement or end of the civil twilight of Lambert, occurs when the sun reaches a zenith distance of 96°." Abbe, sr.,[27] gives a similar definition, except that he does not give the position of the sun. Kaemtz [28] distinguishes astronomical from ordinary twilight, the latter terminating "when darkness compels us to suspend labour that is going on in the open air." Láska's definition is similar, except that he adds that the sun is then about 6½° below the horizon. Bezold [29] identifies the end of civil twilight with the disappearance of the first purple light, when the sun is about 6° below the horizon. This is also Gruner's definition.[30] Flammarion [31] states that civil twilight ends and the day closes at the moment when the sun is 6° below the horizon, and the planets and stars of the first magnitude begin to appear. In the Annuaire Astronomique de l'Observatoire Royal de Belgique [32] it is stated that civil twilight ends when the sun is about 6° below the horizon, at the time the [anti]crepuscular arch passes the zenith. Heim [33] states that with a depression of the sun of 6½° civil twilight ends; that is to say, one can no longer read and write without artificial light. According to Vincent [34] civil twilight begins in the morning at the instant when we are first able to read ordinary print with the back turned toward the east; the sun is then 6° below the horizon. It ends in the evening when we cease to be able to read with the back turned toward the sun's setting. A note in the Journal of the Royal Astronomical Society of Canada, May, June, 1916, p. 265, also gives as the end of civil twilight the moment when the [anti]*crepuscular curve* passes the zenith, and planets and stars of the first magnitude begin to appear, the depression of the sun below the horizon being about 6°.

It thus appears that five distinct definitions are given for the ending of civil twilight in the evening or its beginning in the morning, as follows:

(1) The moment when the anticrepuscular, or anti-twilight arch passes the zenith.

[23] Marvin, C. F. Sunshine Tables. Edition of 1905, p. 3. (W. B. No. 320.)

[24] Ball, Frederick. Altitude Tables for lat. 31° to 60°. London, 1907; [same] for lat. 0° to 30°, London, 1910.

[25] Lambert's value for this depression is 6° 23′. See Lambert, op. cit., p. 108. The writer is unable to confirm Lambert's use of the terms civil twilight and twilight arch in this connection, although both terms are repeatedly attributed to him.

[26] Bravais, M. A. Observations crépusculaires faites en Suisse, à une élévation de 2,690 mètres au-dessus de la mer. Comptes Rendus, 1884, 18:728.

[27] Abbe, Prof. Cleveland. Notes from the reports of State sections. MONTHLY WEATHER REVIEW, March 1898, 26:114–15.

[28] Kaentz, op. cit., p. 409.

[29] Bezold, Wilhelm von. Beobachtungen über die Dämmerung. Gesammelte Abhandlungen aus den Gebieten der Meteorologie und des Erdmagnetismus. Braunschweig, 1906, p. 29. See also Abbe's translation, this separate, p. 20.

[30] Gruner, P. Nouvelles remarques concernant les lueurs crépusculaires du ciel. Arch. d. sci. phys. et nat., Geneva, 1916, 4me, per., t. 42, p. 39.

[31] Flammarion, op. cit., 1893, p. 29.

[32] See, for example, the Annuaire for 1907, p. 193.

[33] Heim, op. cit. p. 63.

[34] Vincent, J. Traité de météorologie. Bruxelles, 1914 p. 54.

(2) The moment when the sun is 6° to 6½° below the horizon. This latter, however, appears to be dependent upon (1).

(3) The moment when stars and planets of the first magnitude are just visible.

(4) The moment in the evening when darkness compels us to suspend labor in the open air, or the moment in the morning when the light is sufficient for its resumption.

(5) With the disappearance of the first purple light in the evening, or with its reappearance in the morning. This, in general, appears to coincide with (2) and observations likewise appear to make it coincide with (3) and (4).

Likewise, there are discrepancies to be found in tables giving the duration of civil twilight. Thus, in the Berliner Astronomisches Jahrbücher for 1776–1783, the tables which give the duration of astronomical twilight (already referred to) also give the duration of civil twilight; or the interval between the time the center of the sun coincides with the true horizon, disregarding atmospheric refraction, and the time its center is 6½°23½′ below the horizon. In the Annuaire Astronomique de l'Observatoire Royal de Belgique [35] is a table giving the duration of civil twilight for every fifth degree of latitude, at the times of the summer and winter solstices and the equinoxes; and the time given is that required for the center of the sun to pass from the horizon to a point 6° below, *true positions being understood.* This table was copied by Exner.[36] In the Annuaire Astronomique et Météorologique, par Camille Flammarion,[37] is a table that gives the time interval between the instant when the *center of the sun appears to be on the true horizon,* allowing for atmospheric refraction, and the instant when its center is 6° below the horizon; and this table has been copied by Láska.[38]

Finally, in the Ephemerides of the Annuaire Astronomique de l'Observatoire Royal de Belgique is given the time of beginning of civil twilight at Uccle, the time of sunrise, the time of sunset, and the time of ending of civil twilight, for each day in the year. The duration of civil twilight as determined from these data agree quite closely with Flammarion's table, although on some days the duration of morning and evening twilight differs by two minutes. The time given for sunrise or sunset is the instant when the center of the sun will appear to be on the true horizon, assuming 34.5′ for atmospheric refraction.

With the exception of the table in the Berliner Astronomisches Jahrbuch, it is seen that all the above are in accord in considering that civil twilight ends in the evening and begins in the morning when the true position of the sun's center is 6° below the horizon; and the differences found in them, as in the case of tables of the duration of astronomical twilight, are to be attributed to differences in the conception of the position of the sun at sunrise or sunset.

The older definition of the beginning or ending of civil twilight, the moment when the anticrepuscular, or antitwilight arch passes the zenith, depends on a phenomenon that can only be observed under the most favorable circumstances.[39] It therefore appears that we should abandon this definition for the newer one of Bezold, namely, the moment when the first purple light disappears from the sky in the evening or reappears in the morning; since under favorable atmospheric conditions this is a prominent feature of twilight phenomena.

We will therefore define the end of civil twilight in the evening and its beginning in the morning as *the instant when the true position of the sun's center is 6° below the horizon.* At this time stars and planets of the first magnitude are just visible. In the evening the first purple light has just disappeared, and darkness compels the suspension of work in the open air unless artificial illumination is provided. In the morning the first purple light is beginning to appear, and the illumination is sufficient for the resumption of outdoor occupations.

Table 2 gives the length of the period between the time when the upper limb of the sun appears to coincide with the true horizon and the time the true position of its center is 6° below the horizon. Allowing 16′ for the sun's semidiameter and 34′ for atmospheric refraction the sun is then only 5°10′ lower than at the time of sunrise or sunset. The length of this interval has been determined in the same manner as the values of astronomical twilight in Table 1. The values of civil twilight thus determined are from 1 to 3 minutes less than the values given by Flammarion, and, likewise, than those that appear in the Ephemerides of the Annuaire Astronomique de Belgique. They are from 3 minutes to 7 minutes less than those given in the above Annuaire for 1907, page 194, which were copied by Exner, and are also less by the same amount than the values given in the table published by me in the Transactions of the Illuminating Engineering Society, 1916 (reprinted in this REVIEW for January, 1916, 44: 13). This latter table gives, as stated in its heading, the time required for the sun to pass from the horizon to a point 6° below, or vice versa.

TABLE 2.—*Duration of civil twilight.* (*Interval between sunrise or sunset and the time when the true position of the sun's center is 6° below the horizon.*)

Date	North latitude														
	0°	10°	20°	25°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
Jan. 1	22	22	24	25	27	27	27	28	29	30	32	33	34	36	39
11	22	22	24	25	26	27	28	28	29	30	31	32	33	35	38
21	22	22	23	24	26	26	27	27	28	29	30	32	33	34	37
Feb. 1	22	22	23	24	25	26	27	27	27	28	29	31	32	34	35
11	22	22	22	23	25	26	26	27	27	28	29	30	31	33	34
21	21	22	22	23	24	25	25	26	27	28	28	29	30	32	33
Mar. 1	21	22	22	23	24	24	25	26	27	28	28	29	30	31	33
11	21	21	22	23	24	24	25	26	26	27	27	29	30	31	32
21	21	21	22	23	24	24	25	26	26	27	27	28	30	31	33
Apr. 1	21	21	22	23	24	25	25	26	27	28	28	29	30	32	33
11	21	22	22	23	24	25	26	26	27	28	28	29	31	32	34
21	22	22	22	23	25	25	26	27	28	28	29	30	32	34	35
May 1	22	22	23	24	25	26	27	28	28	29	30	32	33	35	36
11	22	22	23	24	26	27	28	29	29	30	31	33	35	36	39
21	22	22	24	25	27	28	28	29	30	31	33	35	36	38	41
June 1	22	22	24	25	27	28	28	29	31	32	34	36	37	40	43
11	22	23	24	26	28	28	29	30	31	33	34	36	38	41	44
21	22	23	25	26	28	29	29	30	31	33	34	36	38	42	44
July 1	22	23	24	26	28	28	29	30	31	33	34	36	38	41	44
11	22	22	24	25	27	28	28	29	31	32	34	36	37	40	43
21	22	22	24	25	27	28	28	29	30	31	33	35	36	38	41
Aug. 1	22	22	23	24	26	27	28	29	29	30	31	33	35	36	39
11	22	22	23	24	25	26	27	28	28	29	30	32	33	35	36
21	22	22	22	23	25	25	26	27	28	28	29	30	32	34	35
Sept. 1	21	22	22	23	24	25	26	26	27	28	28	29	31	32	34
11	21	21	22	23	24	25	25	26	27	28	28	29	30	31	33
21	21	21	22	23	24	24	25	26	27	27	27	28	30	31	33
Oct. 1	21	21	22	23	24	24	25	26	26	27	27	29	30	31	32
11	21	22	22	23	24	24	25	26	27	28	28	29	30	31	33
21	21	22	22	23	21	25	25	26	27	28	28	29	30	32	33
Nov. 1	22	22	22	23	25	25	26	27	28	28	29	30	31	33	34
11	22	22	23	24	25	26	27	28	28	29	30	31	32	33	35
21	22	22	23	24	26	26	27	28	28	29	30	32	33	34	37
Dec. 1	22	22	24	25	26	27	28	28	29	30	31	33	34	35	38
11	22	22	24	25	27	27	28	28	29	30	32	33	34	36	39
21	22	23	24	25	27	27	28	28	29	31	32	33	34	37	39

[35] See, for example, the Annuaire for 1907, p. 194.

[36] *Pernter & Exner*, op. cit., p. 745.

[37] See, for example, the Annuaire for 1893, p. 39.

[38] *Láska*, op. cit., p. 77.

[39] One of the few authentic observations of the transit of the "upper boundary of the earth's shadow" was made by Heim from a steamer in the Indian Ocean. See Heim Luft-Farben, p. 75.

Applying the duration of astronomical or civil twilight, as given in tables 1 and 2, to the time of sunrise or sunset as derived from Weather Bureau Sunshine Tables [40] we may obtain the time of the ending in the evening or of the beginning in the morning of either astronomical or civil twilight as desired.

THE INTENSITY OF TWILIGHT

With a standard photometer we may measure the intensity of the illumination at intervals during the twilight period, and this has been done by the writer at Mount Weather, Va.,[41] and later, with the same photometer, by Mr. A. H. Thiessen at Salt Lake City, Utah. The results are summarized in table 3, and are shown graphically in figure 1. The sun's altitude refers to the true position of its center, and has been determined from Ball's Altitude Tables, already referred to.

It is to be understood that the discussion which follows refers to a practically cloudless sky, unless otherwise stated.

TABLE 3.—*Photometric measurements of twilight illumination*

Mount Weather, Va.						Salt Lake City, Utah			
Nov. 4, 1913		Nov. 5, 1913		Nov. 6, 1913		Dec. 15, 1914		May 17, 1916	
Sun's altitude	Illumination	Sun's altitude	Illumination	Sun's altitude	Illumination	Sun's altitude	Illumination	Sun's altitude	Illumination
°	*Foot-candles*	°	*Foot-candles*	°	*Foot-candles*	°	*Foot-candles*	°	*Foot-candles*
				±0.0	98	−0.6	41.9*h*	+0.5	57.8
−0.6	37					−1.1	20.0	−0.5	32.8
−1.9	13	−1.4	57	−2.0	27	−4.0	1.6*h*	−1.0	23.6*h*
		−2.9	14	−4.2	3	−4.8	0.4	−1.6	17.7
						−5.2	0.12*h*	−1.7	15.2*h*
				−5.9	0.4	−6.2	0.07	−2.2	9.4

Salt Lake City, Utah							
June 6, 1916		June 7, 1916		June 10, 1916		June 29, 1916	
Sun's altitude	Illumination	Sun's altitude	Illumination	Sun's altitude	Illumination	Sun's altitude	Illumination
°	*Foot-candles*	°	*Foot-candles*	°	*Foot-candles*	°	*Foot-candles*
+0.1	95.8	+0.5	57.8	+0.5	55.6	+1.6	97.7
−1.2	34.5	−0.8	58.3*h*	+0.2	46.4	+1.1	76.8
−1.8	37.1*h*	−1.1	33.2	−0.2	45.6	+0.8	66.8
−2.6	16.6	−1.6	55.6*h*	−1.0	25.7	−0.2	51.0
−3.0	18.3*h*	−1.8	24.5	−1.4	18.3*h*	−0.7	29.7
−3.8	7.8 (*a*)	−1.9	30.8*h*	−2.1	15.4	−1.0	29.8
−4.4	4.2*h*	−2.7	8.0	−2.2	18.2*h*	−1.3	30.3*h*
−6.6	0.63	−3.0	11.8*h*	−3.0	6.4	−1.8	19.5
−7.4	0.62*h*	−4.1	2.3	−3.2	7.4*h*	−2.6	16.5*h*
		−4.4	4.5*h*	−3.6	2.8	−2.9	8.3
		−4.7	1.6	−3.8	2.7*h* (*b*)	−3.1	13.6*h*
		−4.9	2.6*h*	−5.2	0.55	−3.4	5.6
		−5.6	0.86	−5.3	1.00*h* (*c*)	−3.5	8.2*h*
		−5.9	0.94*h*	−6.2	0.20	−3.7	4.2
		−6.5	0.20	−6.4	0.32*h*	−4.2	4.4*h*
		−6.7	0.46*h*	−7.3	0.062	−4.4	2.0
		−7.3	0.078	−7.4	0.118*h*	−4.6	2.6*h*
		−7.4	0.186*h*	−8.3	0.015	−4.8	1.4
		−8.3	0.037	−8.6	0.034*h* (*d*)	−6.9	0.14*h*
		−8.6	0.069*h*	−9.0	0.008	−8.0	0.047 (*e*)
		−9.5	0.015	−9.3	0.016*h*	−8.6	0.063*h*
		−9.6	0.027*h*			−10.8	0.004
		−10.0	0.008			−11.4	0.007*h*
		−10.3	0.023*h*				

Remarks on table 3.—At Mount Weather the sun appeared to set when the true position of its center was about 0.7° below the horizon. At Salt Lake City, on December 15, 1914, it appeared to set when the true position of its center was 2.8° above the horizon; and in May and June, 1916, when the true position of its center was about 0.3° below the horizon.

At Mount Weather on November 4, 1913, dense haze prevailed, and at sunset the sun disappeared in a bank of haze; while on November 5 and 6 the sky was clear and the twilight colors were brilliant—yellow with purple light, followed by red.

At Salt Lake City, on December 15, 1914, the sun set clear; on May 17, 1916, the sun was obscured at sunset by Ci.St. clouds, which covered about half the sky; on June 6, 7, and 10 the sky was clear; on June 29 there were a few Ci.St. clouds in the west.

h indicates illumination intensities measured with the photometer tube pointed toward the western horizon; all others were measured with tube pointed toward the zenith.

June 6—(*a*) Moon at 45° altitude.

June 10—(*b*) Venus appeared; (*c*), first star in NE.; (*d*), North Star discernible.

June 29—(*e*) Dipper plainly discernible.

[40] *Marvin, C. F.* Sunshine Tables. Edition of 1905. Washington, 1905. (W. B. No. 320.)

[41] *Kimball, Herbert H.* Photometric determinations of daylight illumination on a horizontal surface at Mount Weather, Va. MONTHLY WEATHER REVIEW, December 1914, 42: 650-653.

From figure 1 and the notes on table 3 it is apparent that the twilight is more intense on clear days than on hazy days, and that a cirrus cloud sheet diminishes the light intensity only slightly. Elevated mountains on the horizon near the point where the sun sets diminish the twilight intensity.

The illumination measurements with the photometer pointed toward the western horizon (*h* in the table) do not become markedly higher than measurements with the photometer pointed toward the zenith until the sun is about 2° below the horizon, or shortly before the first purple light begins to appear. The measurements show no increase in illumination during the prevalence of this light. In this respect they are in accord with Gruner's [42] measurements, and disprove many eye observations of an apparent increase in illumination at this time. This apparent increase must be attributed to light contrasts. That part of the sky covered by the first purple light has increased in brightness since sunset, as compared with other parts, and, in consequence, at this time the outlines of buildings and of mountains facing this light stand out with unusual clearness.

From figure 1 it is seen that when the upper limb of the sun appears to coincide with the true horizon (depression of the sun's center 50′) the zenith illumination is about 33 foot-candles. At the end of civil twilight the illumination is about 0.4 foot-candle.

To the unscientific reader light intensities expressed in units of illumination, as above, have little significance. It will therefore be useful to express these intensities in another way.

TABLE 4.—*Photometric measurements of moonlight illumination, Salt Lake City, Utah*

Photometer tube pointed toward the zenith						Photometer tube pointed toward moon			
June 13, 1916		June 14, 1916		June 15-16, 1916		June 14, 1916		June 15-16, 1916	
105th meridian time	Illumination	105th meridian time	Illumination	105th meridian time	Illumination	105th meridian time	Illumination	105th meridian time	Illumination
H. m.	*Foot-candles*	*H. m.*	*Foot-candles*	*H. m.*	*Foot-candles*	*H. m.*	*Foot-candles*	*H. m.*	*Foot-candles*
9:02 p	0.00451	9:10 p	0.00303*a*	10:28 p	0.00358	11:40 p	0.0127	10:34 p	0.0129
9:13 p	0.00458	9:25 p	0.00400	10:50 p	0.00434	11:53 p	0.0117	10:47 p	0.0127*e*
9:32 p	0.00370	9:43 p	0.00443	11:01 p	0.00546			10:39 p	0.0131*f*
9:34 p	0.00382	9:58 p	0.00424*b*	11:19 p	0.00601			Midn't	0.0143
9:36 p	0.00496	10:14 p	0.00409	11:35 p	0.00555			12:42 a	0.0171
9:41 p	0.00419	10:28 p	0.00424	12:05 a	0.00574			12:45 a	0.0185*g*
10:01 p	0.00468	10:45 p	0.00405*c*	12:24 a	0.00569			12:52 a	0.0174
10:03 p	0.00468	11:00 p	0.00426	12:38 a	0.00574				
10:15 p	0.00415	11:15 p	0.00514	12:55 a	0.00707				
10:17 p	0.00420	11:33 p	0.00491	12:58 a	0.00707				
10:29 p	0.00464	11:47 p	0.00541						
10:31 p	0.00582	Midn't	0.00528*d*						
10:35 p	0.00455								

[42] *Gruner, P.* Quelques remarques concernant les lueurs crépusculaires du ciel. Arch. sci. phys. et nat., Geneva, 1914, 37(42): 226-248.

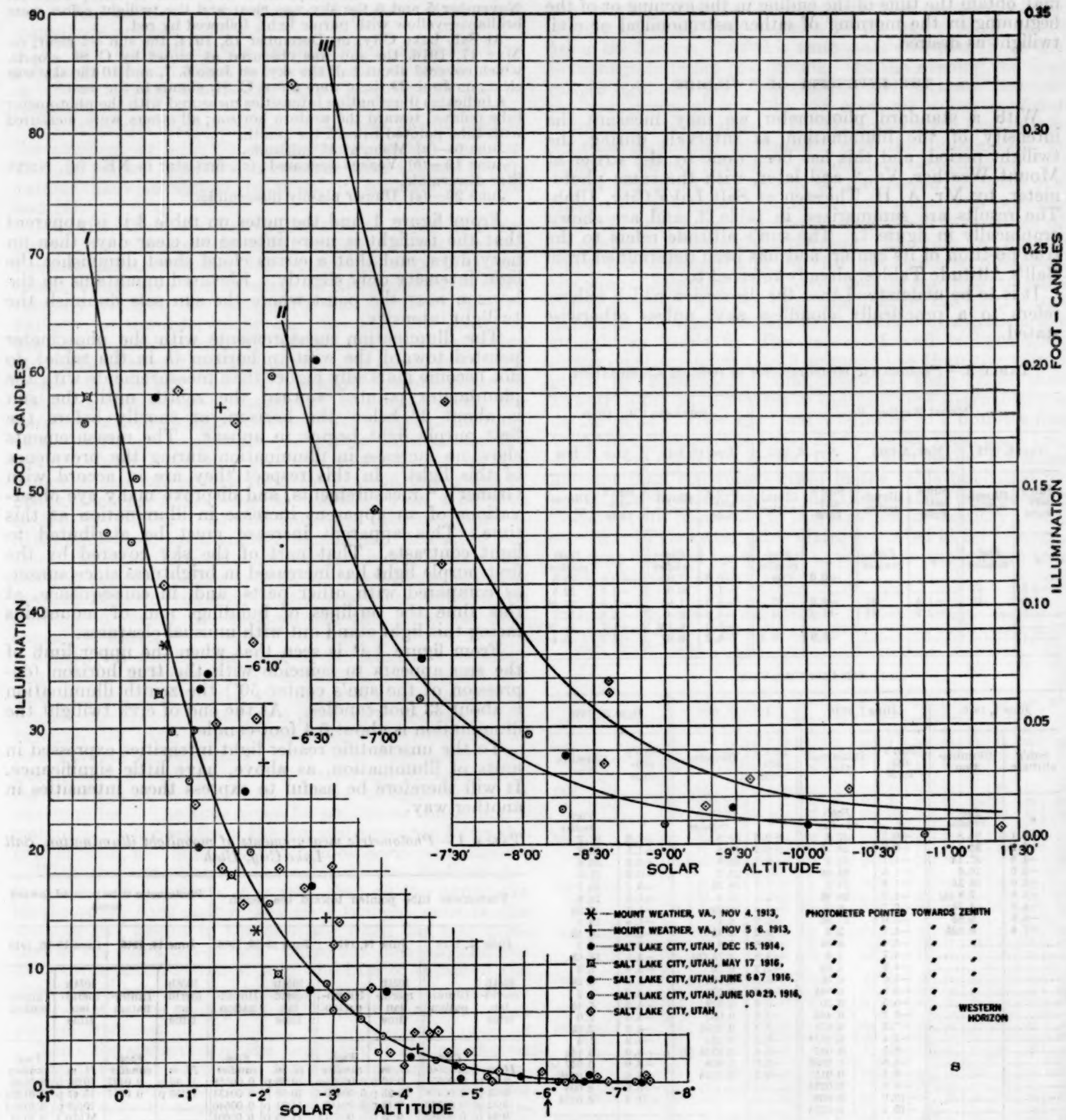


FIG. 1. Photometric measurements of twilight illumination.

Curve I, photometer pointed toward the zenith.
Curve II (insert), continuation of Curve I on more open scale with observations of June 7, 10, and 29, 1916.
Curve III, photometer pointed toward western horizon.
↑ End of civil twilight. True position of sun, 6° 0' below the sensible horizon.

Remarks on table 4.—Clear skies prevailed on all three nights. Moon full, June 15, 1916, at 2:42 p. m. Moon on meridian, June 13, 10:44 p. m.; June 14, 11:48 p. m.; June 16, 12:54 a. m. Moon's declination, from −25° to −26°.

NOTES

June 14:
- *a.* 18-point type read with ease; 8-point type read with difficulty.
- *b.* 12-point type read with ease; 6-point type read with difficulty.
- *c.* 10-point type read with ease; 5½-point type read with difficulty.
- *d.* 9-point type read with ease.

June 15–16:
- *e.* 14-point type read with ease; 10-point type read with difficulty.
- *f.* 14-point type read with ease; 10-point type read with difficulty.
- *g.* 12-point type read with ease; 10-point type read with difficulty.

Century expanded type on white paper was used, and the sizes used are illustrated below.

18-point Century expanded type

14-point Century expanded type

12-point Century expanded type

10-point Century expanded type

*10-Point Roman type

8-point Century expanded type

6-point Century expanded type

* 5-point Roman type

* Approximately 9-pt. and 5½-pt. "Century," respectively.

From two papers by Russell [43] we are able to compare the intensities of sunlight, twilight, moonlight, and starlight with considerable accuracy. Thus, Russell [44] gives the stellar magnitude of the zenith sun as -26.72 ± 0.04 and the stellar magnitude of the zenith moon [45] as -12.55 ± 0.07. The difference in these stellar magnitudes is 14.17. A difference of one stellar magnitude represents light intensities in the ratio of 1:2.512. Therefore, the sun exceeds the moon in brightness 465,000 times. From Weather Bureau photometric measurements made at Mount Weather, Va., Russell [46] obtains for the zenith sun a light intensity of 9,600 foot-candles, or 9.96 stellar magnitudes brighter than a foot-candle, and gives for the foot-candle a stellar magnitude of −16.76. This is 4.21 stellar magnitudes, or 48.3 times, brighter than the full moon in the zenith.

This result is in good accord with recent measurements made by Thiessen, which are summarized in Table 4. For the total moonlight illumination we must add about 10 percent for diffuse sky radiation, so that the illumination from the full moon in the zenith as compared to a foot-candle is about 1:43.5. With the moon 66.5° from the zenith its illumination is about 70 per cent of its zenith illumination, and the proportion to a foot-candle is about 1:62, which is very close to Thiessen's value with the photometer pointed toward the full moon, the zenith distance of the latter being about 66°. According to Russell [47] the illumination of the moon in its first or last quarter is about one-tenth of the full-moon illumination.

[43] Russell, Henry Norris. Stellar magnitudes of the sun, moon, and planets. Astrophysical journal, March 1916, 43:103–129.
On the albedo of the planets and their satellites. Ibid., Apr. 1916, 43:173–196.
[44] Op. cit., p. 105.
[45] Op. cit., p. 125.
[46] Op. cit., p. 126–129.
[47] Op. cit., p. 117.

From papers by Fabry [48] and Yntema [49] it appears that the total starlight of a hemisphere is somewhat in excess of 1,000 stars of the first magnitude, or about 1/250th of the brightness of the full moon.

From the above data Table 5 has been constructed.

TABLE 5.—*Relative illumination intensities*

Source of illumination	Intensity	Ratio to zenithal full moon
	Foot-candles	
Zenithal sun	9,600.0	465,000.0
Sky at sunset	33.00	1,650.0
Sky at end of civil twilight	0.40	20.0
Zenithal full moon	0.02	1.0
Quarter moon	0.002	0.1
Starlight	0.00008	0.004

From table 5 and figure 1 it appears that the twilight illumination exceeds the illumination from the zenithal full moon until the sun's center is about 8° 40′ below the horizon. As this is an illumination intensity of some interest, the time after sunset or before sunrise when the center of the sun will be 8° 40′ below the horizon is given in table 6 for certain latitudes at the time of the equinoxes and the solstices.

TABLE 6.—*Time after sunset, or before sunrise, during which the twilight intensity exceeds zenithal full-moonlight*

Latitude	Winter solstice	Equinoxes	Summer solstice	Latitude	Winter solstice	Equinoxes	Summer solstice
°	*H. m.*	*H. m.*	*H. m.*	°	*H. m.*	*H. m.*	*H. m.*
0	0 35	0 31	0 35	38	0 44	0 40	0 49
10	0 35	0 32	0 35	40	0 46	0 41	0 51
20	0 36	0 33	0 37	42	0 48	0 42	0 54
25	0 38	0 35	0 39	44	0 50	0 44	0 57
30	0 40	0 36	0 42	46	0 52	0 45	1 00
32	0 41	0 37	0 43	48	0 54	0 47	1 05
34	0 42	0 38	0 45	50	0 57	0 49	1 11
36	0 43	0 39	0 47				

SUMMARY

1. A review of the literature indicates that from an early date *astronomical* twilight has been considered to end in the evening and begin in the morning when the true position of the sun's center is 18° below the horizon. At this time stars of the sixth magnitude are visible near the zenith, and generally there is no trace on the horizon of the twilight glow.

2. It also appears that *civil* twilight ends in the evening and begins in the morning when the true position of the sun's center is 6° below the horizon. At this time stars and planets of the first magnitude are just visible. In the evening the first purple light has just disappeared, and darkness compels the suspension of out-door work unless artificial lighting is provided. In the morning the first purple light is beginning to be visible, and the illumination is sufficient for the resumption of out-door occupations.

3. Some confusion has arisen in the computation of tables of the duration of both astronomical and civil twilight, due to the fact that in some instances the time of sunrise or sunset has been considered to be that instant when the *center* of the sun is on the true horizon; in others, when its center *appears* to be on the true horizon; and in still others when the *upper limb* of the sun appears to coincide with the true horizon. In the

[48] Fabry, Charles. The intrinsic brightness of the starlit sky. Astrophysical journal, 1910, 31:399.
[49] Yntema, Lambertus. On the brightness of the sky and the total amount of starlight. Groningen, 1909. 4° p. 37.

United States this latter is regarded as defining the time of sunrise and sunset.

4. In the tables here presented the duration of astronomical twilight is the interval between sunrise or sunset, according to this latter definition, and the instant the true position of the sun's center is 18° below the horizon. Likewise, the duration of civil twilight is the interval from sunrise or sunset to the instant the true position of the sun's center is 6° below the horizon.

5. At the instant of sunrise or sunset the illumination is about 1,650 times as intense as that from the zenithal full moon; at the end of civil twilight it is about 20 times as intense; with the sun 8° 40′ below the horizon it about equals zenithal full moon illumination; while at the end of astronomical twilight, in the absence of the moon, it is only about 0.004 as intense.

The above refer to average clear sky conditions. The twilight will be more intense in a dry climate than in a moist one, will be greatly reduced by smoke or haze, and may be almost completely obliterated by a dense cloud layer. On the other hand, the intensity may be increased by the presence of ice crystals in the atmosphere, especially if they are at a considerable elevation above the place of observation.

I wish to acknowledge my indebtedness to the editor, Dr. Cleveland Abbe, Jr., for valuable assistance in reading many of the foreign books and papers consulted in the preparation of this paper, and to Prof. C. F. Talman for his criticism of the manuscript, and for bringing to my attention certain publications that had been overlooked.

HURRICANE OF SEPTEMBER 16 TO 22, 1938

By I. R. TANNEHILL

[Marine Division, Weather Bureau, Washington, October 1938]

This hurricane was first definitely located from radio reports on the evening of September 17, when it was centered approximately 500 miles northeast of the Leeward Islands, but mail reports now at hand show that it was centered at about 21° N., 53° W. late on the 16th. Its subsequent course is shown on chart IX. On September 21 the center passed over Long Island and into New England near New Haven. Loss of human life was placed at about 600; the total value of property destroyed in the affected areas has been conservatively estimated at a quarter to a third of a billion dollars.

TROPICAL STORMS IN NEW ENGLAND

Many storms of tropical origin have previously affected the New England States. Some of them have crossed the Gulf coast, approaching New England from the southwest, usually with diminishing force; in greater numbers, they have skirted the Atlantic coast with their centers over the ocean, causing gales along the seaboard; a few have retained hurricane force in their progress northward and have been destructive in the interior of the New England States.

Perhaps the earliest of the severe tropical storms of record in New England was that which occurred on August 15, 1635. A strong northeast wind with heavy rain began before daybreak, increased in violence and was accompanied by torrential rain. After the gale had continued 5 or 6 hours, it changed to northwest and gradually subsided. In the same month there was a hurricane, possibly the same one, between St. Kitts and Martinique, exact date unknown, and also a violent gale on the coast of Haiti. Of the New England storm of the 15th, Governor Bradford said: "None then living, either English or Indian, ever saw a storm equal to it." [1]

The "Great September Gale" of 1815 is probably the most noted of the early storms of New England. It was generally destructive in Rhode Island and in the central portion of Massachusetts. On the coast of Connecticut the high tides and hurricane winds destroyed many buildings, and numerous vessels were driven ashore. The storm set in from the northeast late on September 22 and reached its height shortly before noon of the following day. This hurricane came from the West Indies. It was recorded at St. Bartholomew on the 18th. Oliver Wendell Holmes was 6 years of age at the time of the storm and afterward immortalized it in his poem, "The September Gale."

Another noteworthy hurricane occurred in New England in 1821. Its course was traced by Redfield.[2] The center of this hurricane crossed the western part of Long Island and passed northward into Connecticut. Shortly afterward, in traveling over the area devastated by this storm, Redfield observed the directions in which the fallen trees were lying and discovered that the storm was a great whirlwind. However, he did not publish the first account of his observations until 1831.[3]

Other storms, probably all of tropical origin, which have seriously affected the New England States,[4] are summarized briefly as follows:

August 19, 1788.—A storm passed northward over eastern New York and western New England. There was considerable damage in Connecticut and western Massachusetts.

September 8, 1869.—This storm appears to have passed over eastern Connecticut, Rhode Island, and eastern Massachusetts with a path about 60 miles wide, then over the ocean to the Maine coast. Many vessels were driven ashore. There was much property damage in eastern Massachusetts and on the Maine coast.

October 23–24, 1878.—Center of the hurricane crossed eastern Pennsylvania and southeastern New York, then turned to the northeast and east across New England. Much damage was reported in New York City, Brooklyn, the Hudson Valley, and Long Island Sound. Several vessels were sunk along the Connecticut coast.

August 24, 1893.—A storm passed over New York City, then northeast across New England. It was severe in Connecticut and Rhode Island.

August 29, 1893.—A storm was severe from New York to the eastern New England coast.

September 16, 1903.—This storm was destructive in the Connecticut Valley; there was extensive damage to shipping on the coast.

From these accounts it appears that the hurricane of September 1938 is not unprecedented in violence in the New England area; but the great increase in population and property values since the early part of the 19th century

[1] Perley, Sydney. Historic storms of New England. Salem. 1891.

[2] Redfield, W. C. On three severe hurricanes of the Atlantic. New Haven. 1846.

[3] Redfield, W. C. Remarks on the prevailing storms of the Atlantic coast, of the North American States. The American Journal of Science and Arts. Vol. XX, pp. 17–51. New Haven. 1831.

[4] From notes furnished by J. M. Kirk, official in charge of the Weather Bureau Office, New Haven, Conn.

accounts for economic losses in the recent hurricane which are probably in excess of all previous hurricanes in that area combined. In fact, the destruction of property in the hurricane of September 1938 was considerably greater than that caused by any other single hurricane in the United States.

The approximate tracks of the centers of the hurricanes of 1815 and 1821 are shown in chart X. Open circles on the tracks indicate noon positions on the dates beside the circles. The track of the hurricane of 1821 is reproduced as it was traced by Redfield. After the hurricane of 1815, Noyes Darling, who lived in New York City, made a collection and abstract of all the newspaper accounts of it that came to his attention. In 1842 he published his collection [5] which contains sufficient information to determine the track of the storm center as it appears in chart X. The hurricane of 1821 moved with unusual rapidity throughout the known path. While the hurricane of 1815 did not move so rapidly in the early part of the track, its progressive motion on the day it entered New England was exceptionally rapid.

THE HURRICANE OF 1938 AT SEA

There was some evidence of cyclonic circulation central about 19° N., 37° W., on the morning of September 13, 1938, but the storm has not been definitely charted prior to the evening of September 16, when it appears to have become a fully developed hurricane. At about 9:30 p. m., ship's time, on September 16, the Brazilian S. S. *Alegrete* was near the center in approximately 21°12′ N., 52°46′ W., barometer 28.31 (uncorrected), wind force 12, shifting from east-northeast to east-southeast. Early on the morning of September 17, the Netherlands S. S. *Socrates* encountered the storm while near 21° N., 59° W., and had increasing winds, backing from east-northeast to northwest and then to west-southwest, lowest barometer 29.29 inches. The highest wind experienced was W–11 at 9:35 p. m., ship's time, in latitude 20°38′ N., longitude 59°17′ W.

During the 17th and 18th, the hurricane moved in a direction only slightly north of west, its progressive motion averaging more than 20 miles an hour. On the 19th and 20th the hurricane recurved, with somewhat slower movement, about 15 miles an hour, until the evening of the 20th when it turned more to the northward and began an increasingly rapid march which culminated in a progressive rate of about 50 miles an hour during the 21st.

Many vessels were heavily involved in the storm during the period from the 18th to 21st. Two vessels reporting by radio gave barometer readings below 28 inches, the British S. S. *Corrales*, 27.90 on the 18th and the British S. S. *Carinthia*, 27.85 on the 20th, but neither has rendered gale reports. A summary of gales, including barometer readings, from other vessels appears in the table accompanying the summary of North Atlantic weather elsewhere in this REVIEW.

It appears that central pressure was near or below 28.00 inches throughout the course of the storm at sea, beginning late on the 16th and continuing until the center moved inland near New Haven on the afternoon of the 21st.

THE HURRICANE IN COASTAL AREAS AND IN NEW ENGLAND

It was not until the early morning of September 21 that the hurricane approached any coastal or island area close enough to be felt seriously. At about 7:30 a. m., E. S. T. of that day, the center was about 75 miles east or slightly north of east from Cape Hatteras, where the barometer reading at that time was 29.30 and the wind velocity 50 miles an hour from the northwest. With the center approximately the same distance east of Atlantic City, at about 1 p. m., the hurricane caused a maximum wind velocity of 61 miles an hour from the west at 12:55 p. m., simultaneously with the lowest barometer reading, 28.99 inches. At Sandy Hook, the lowest reading was 28.71 inches, shortly after 2 p. m., maximum wind 56 N. at 1 p. m. The calm center was felt at Brentwood, Long Island, between 1:50 p. m. and 2:50 p. m. Drizzling rain was reported at intervals, with the sun shining during two or three 5-minute periods. The wind movement was so slight during this time that "a cigarette could have been lighted in the open without difficulty." Minimum pressure readings (uncorrected) below 28.00 inches were recorded at points on Long Island.

Shortly before 4 p. m. the center reached the Connecticut coast, passing between New Haven and Bridgeport; lowest pressure at New Haven was 28.11 at 3:50 p. m. At Hartford the minimum pressure, 28.04, was reached at 4:30 p. m.

Moving at a very rapid rate, the center crossed Vermont between 6 and 9 p. m., its course having changed from north by east to north by west, while crossing Massachusetts. At Northfield the lowest barometer reading was 28.77 at 7:30 p. m. and at Burlington 28.68 at 8 p. m.

DESTRUCTIVE EFFECTS OF THE HURRICANE

Owing to the unusually rapid rate of progress of the storm across New England, the winds on the right or east side of the path were very destructive while strong winds did not extend far to the westward. Maximum wind velocities (5-minute intervals) were reported from Weather Bureau stations as follows:

Albany	42 W.	Nantucket	52 SE.
Block Island	82 SE.	New Haven (city)	38 NE.
Boston (airport)	73 S.	New York (City)	70 NW.
Burlington	47 S.	Northfield	47 S.
Concord	56 SE.	Portland	43 S.
Eastport	32 SE.	Providence	87 SW.
Hartford	46 NE.		

At Blue Hill Observatory, Milton, Mass., the maximum 5-minute velocity was 121 miles an hour and for shorter intervals the wind velocity was indicated to be 173 for one measurement and 183 for another. At the observatory on Mount Washington the 5-minute maximum was 136. The higher velocities at these stations, as compared with Weather Bureau offices, are attributed to the effect of upslope at Blue Hill and to the elevation of the Mount Washington station.

Along the shores of Long Island and New England, rises of water caused by the hurricane winds exceeded all records at a number of points. Furthermore, the rivers in the Connecticut and Merrimac Valleys were already practically bank full at the time the hurricane rains began. Over most of this area rain had been falling for about a week. The hurricane rains produced disastrous floods which will be reported in the next issue of the REVIEW.

The winds damaged buildings and broke off or uprooted trees in all parts of the area traversed by the storm center, and to a distance of about 100 miles to the eastward. Damage to buildings and trees did not extend far to the westward of the path. Destruction of property was especially heavy on the shores of Connecticut, Rhode Island, and southern Massachusetts and Long Island.

[5] Darling, Noyes. Notice of a hurricane that passed over New England in September 1815. The American Journal of Science and Arts. Vol. XLII, pp. 243-252. New Haven. 1842.

The extreme eastern and extreme western portions of Massachusetts and the western interior of Connecticut suffered relatively little.

THE INUNDATION

Damage to property along the coast was largely due to the storm wave. At Sandy Hook the tide was 8.2 feet above mean low water; at the Battery, New York City, it was 6.44 feet above mean sea level. Along the coast of Connecticut, Rhode Island, and on the shores of Naragansett and Buzzards Bays, the highest tide ranged from 12 to 25 feet above mean low water, being highest on the southern shores of Massachusetts, where the maximum stage occurred about 5 or 6 p. m. At Point Judith Coast Guard Station the water rose 18 feet above mean low water; at Fairhaven it was estimated at 25 feet; at Pocasset, 20 feet; at the Nobska Point Light Station, 15 feet. At Fall River it was reported that "the water came up rapidly in a great surge," the crest being estimated at "18 feet above normal."

The storm tide, combined with the hurricane winds, raised havoc with small craft and was very destructive to harbor, resort, and beach property.

DAMAGE AND LOSS OF LIFE

The American Red Cross reported on October 27 that 488 lives were lost in the hurricane, 100 persons were missing, 1,754 were injured more or less severely and 93,122 families had suffered more or less serious economic losses. The number of summer dwellings destroyed was placed at 6,933, and other dwellings at 1,991. Boats destroyed numbered 2,605, barns 2,369, and other buildings 7,438.

Estimates of the total economic losses, in all the areas affected, ranged from $250,000,000 to $330,000,000.

WARNINGS

The first advisory warning was issued from the forecast center at Jacksonville at 9:30 p. m. of September 17, when the hurricane was about 500 miles northeast of the Leeward Islands. Advisory messages were issued at 6-hour intervals thereafter. By 9:30 a. m. of September 19, the hurricane had approached within 650 miles of the southern Florida coast and was moving west-northwestward at a rate of about 25 miles an hour; northeast storm warnings were then ordered from Key West to Jacksonville. Later in the day it became evident that the hurricane had turned more to the northward, hence hurricane warnings were not ordered for the Florida coast. At 9:30 a. m. of September 20, storm warnings were ordered displayed on the coast south of Hatteras to Wilmington. At that time the Washington forecaster ordered storm warnings south of the Virginia Capes to Hatteras.

At 9:30 p. m. of September 20, when the hurricane was centered about 400 miles east of Jacksonville, storm warnings were ordered by the Washington forecaster for the area from the Virginia Capes to Atlantic City; and on the morning of September 21, with the center 75 miles east of Hatteras, warnings were extended from Atlantic City to Eastport, Maine. At 10 a. m. storm warnings were changed to whole-gale warnings from the Virginia Capes to Sandy Hook, and at 2 p. m. the last warning was issued, stating that the storm would likely pass over Long Island and Connecticut in the late afternoon or early night.

A further report on the meteorological aspects of this storm will appear in a later issue of the REVIEW.

NOTES AND REVIEWS

W. KÖPPEN und R. GEIGER. *Handbuch der Klimatologie.* Band IV. Teil T: G. SCHOTT, Klimakunde der Südsee-Inseln. Teil U: W. MEINARDUS, Klimakunde der Antarktis. Berlin; Borntraeger, 1938.

This volume is a further addition to the Köppen-Geiger series on climatology and the climates of the world. The complete work will comprise 5 large volumes in 26 parts. The authors are 35 climatologists of various nationalities; the editors W. Köppen and R. Geiger. Parts which have previously come from the press in the last 10 years treat the climates of North, Central and South America, the West Indies, Europe, Australia, New Zealand, the East Indies, and parts of Africa; there has also appeared a volume on general climatology (Band I).

Part T, like others of the series which previously have come from the press, contains a general description of the area treated and a broad view of its climate. This is followed by a detailed presentation of the climates of several zones: I. The Hawaiian Islands; II. The moist equatorial zone; III. The dry equatorial zone; IV. Islands in the southeast trades; V. Islands in the border zone between the southeast trades and prevailing westerlies. The entire region extends from 30° N. to 30° S., and from 105° W. to 135° E.

The tables, occupying 22 pages, give data for 91 stations on Pacific Islands.

Part U presents a description of the Antarctic, a statement regarding the sources of observations, and a discussion of the climatic elements and their distribution, including temperature, pressure and wind, cloudiness, and precipitation; also individual treatments of conditions in selected areas. There is also a large amount of data in tables, based principally, of course, on short records of various expeditions.

Both parts, T and U, contain numerous references to the literature on climatology of the regions discussed.—*I. R. Tannehill.*

BIBLIOGRAPHY

By AMY P. LESHER

[RICHMOND T. ZOCH, in Charge of Library]

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

Amelung, Walther.

Klimatologische Übersicht. [Leipzig.] [1934.] p. 230–234. 25½ cm. (From Fortschritte der Therapie. 10. Jahrgang, Heft 4. April 1934.)

Brooks, Charles F.

A 5-year program of research and instruction in aerology and aeronautical meterorology. [Milton, Mass. 1937.] 1 p. 28 cm. (Blue Hill meteorological observatory, Milton, Mass.) [Reprinted from Transactions of the American geophysical union, 18th annual meeting, 1937.]

Eblé, L.

Sur la température du sol. Ann. agron. n. s. année 6, p. 659–676. Paris. 1936. "Bibliographie sommaire": p. 675–676.

Ellsberg, Edward.

Hell on ice; the saga of the "Jeannette," New York. 1938. x,-,421 .p. illus. (inc. map). 22 cm. Map on lining-papers. The personal narrative in fictional form of the chief engineer of the expedition, G. W. Melville.

Fritzsche, Gerhard.

Untersuchungen über die von Maschinen, Fahrzeugen und Wind hervorgerufenen Boden- und Gebäudeerschütterungen nach Registrierungen eines Benioff-Vertikal-Seismographen. Leipzig. 1937. 81 p. Illus., tabs., diagrs. 24½ cm. (Veröffentlichungen des Geophysikalischen Instituts der Universität Leipzig. Zweite Serie. Spezialarbeiten aus dem Geophysikalischen Institut und Observatorium. Bd. X, Anhang 1.)

Germany. Reichsamt für Wetterdienst.

Wissenschaftliche Abhandlungen. Berlin. 34 cm.

v. 1, no. 1. Robitzsch, M. Klima und Organismus. 1935. 17 p.

v. 1, no. 2. Kähler, K. Luftelektrische Messungen während des internationalen Polarjahres 1932/1933 in Potsdam. 1935. 38 p. tables, diagrs.

v. 1, no. 3. Urban, E. Verteilung der Niederschlagshäufigkeit zu Potsdam und Versuch ihrer analytischen Behandlung. 1935. 18 p. tables, diagrs.

v. 1, no. 4. Brose, K. Der jährliche Gang der Windgeschwindigkeit auf der Erde. 1936. 78 p. plate (fold. maps), tables, diagrs.

v. 1, no. 5. Riedel, G. Singularitäten des Davoser Klimas. 1936. 27 p. tables, diagrs. (1 fold.)

v. 1, no. 6. Egersdörfer, R., & L. Formeln und Tabellen der zugeordneten Kugelfunktionen 1. Art von n=1 bis n=20. 1936. 67 p.

v. 1, no. 7. Grebe, H. Die Temperaturverhältnisse in Jena von 1770 bis 1935, ein Beitrag zur Witterungsgeschichte von Mitteldeutschland. 1936. 71 p. tabs.

v. 1, no. 8. Schell, H. Klima, Witterung und Weinbau. 1936. 16 p. tables, diagrs.

v. 1, no. 9. Kreutz, W., & Rohweder, M. Korrelationsanalyse des Temperatur- und Feuchtigkeitsverlaufes in extrem verschiedenen Böden und in der bodennahen Luft. 1936. 20 p. tables, diagrs.

v. 2, no. 1. Schmausz, A. Die interdiurne Veränderlichkeit der Temperatur auf der Zugspitze. 1936. 26 p. tables, diagrs.

v. 2, no. 2. Süring, R. Auszüge aus deutschen Wolkentagebüchern aus der Zeit des zweiten Internationalen Polarjahres August 1932 bis August 1933. Zusammengestellt von R. Süring. 1936. 81 p. tables.

v. 2, no. 3. Philipps, H. Die Störungen des zonalen atmosphärischen Grundzustandes durch stratosphärische Druckwellen. 1936. 52 p. diagrs. (Aus der Forschungsstelle für langfristige Wettervorhersage des Reichamts für Wetterdienst zu Bad Homburg v. b. H.)

Germany. Reichsamt für Wetterdienst—Continued.

v. 2, no. 4. Alt, E., & Fickert, R. Die Hochwasserkatastrophe im östlichen Erzgebirge am 8. bis 9. Juli 1927. 1. Meteorologische Voraussetzungen. Von E. Alt. 2. Die Niederschläge. Von R. Fickert. 1936. 15 p. Mit 6 Kartenbeilagen. tables.

v. 2, no. 5. Dreyling, H. Das Auftreten von Bergnebel in Abhängigkeit von der Windrichtung. Eine Untersuchung über die Nebelverhältnisse auf mitteleuropäischen Gebirgsgipfeln. 1936. 19 p. tables, diagrs. (Aus dem Universitätsinstitut für Meteorologie und Geophysik in Frankfurt a. M.)

v. 2, no. 6. Mäde, A. Widerstandselektrische Temperaturmessungen in einem Topinamburbestand. 1936. 23 p. tables, diagrs. (Aus der Agrarmeteorologischen Forschungsstelle des Reichsamts für Wetterdienst in Müncheberg. [Mark].)

v. 2, no. 7. Kreutz, W. Agrarmeteorologische Studien über Bestandsklima, über Windschutz und über Transpirationsverhältnisse im Gewächshaus. Mit 2 Tafeln. 1937. 42 p. tables, diagrs. (Aus der Agrarmeteorologischen Forschungsstelle des Reichsamts für Wetterdienst in Gieszen.)

v. 2, no. 8. Damman, W. Nasse und trockene Perioden im Harz in abhängigkeit von der Wetterlage. Mit 3 Tafeln. 1937. 33 p. tables, diagrs. (Aus dem Geographischen Institut der Universität Göttingen.)

v. 2, no. 9. Agricola, A. Über die Aufstellung der Thermometerhütte auf der Zugspitze. 1937. 16 p. tables, diagrs.

v. 2, no. 10. Israël-Kohler, H. Das Emanationsdosimeter. Ein Gerät zur Dauerkontrolle mässig hoher Emanationskonzentrationen in Luft. 1937. 15 p. tables, diagrs.

v. 2, no. 11. Findeisen, W. Neue Wege der meteorologischen Feuchtigkeitsmessung. 1937. 44 p. tables, diagrs.

v. 3, no. 1. Haude, W., *& others.* Ergebnisse von Nebel-Untersuchungen in Schlesien während des Frühjahrs 1936. Von W. Haude, O. Moese, G. Reymann. Mit 4 Tafeln und 20 Karten. 1937. 24 p. tables, diagrs.

v. 3, no. 2. Keil, K. Ergebnisse der deutschen Höhenwindmessungen während des zweiten Internationalen Polarjahres 1932/1933. 1937. 107 p. tables.

v. 3, no. 3. Dinies, E. Der Aufbau von Steig- und Fallgebieten. 1937. 16 p. tables, diagrs.

v. 3, no. 7. Peppler, W. Temperaturen des Wassers und der Luft auf dem Bodensee. 1937. 38 p. tables, diagrs.

v. 3, no. 8. Berg, H. Wolkenschichtung und Wolkenstruktur. 1937. 33 p. tables, diagrs.

v. 3, no. 9. Knockenhauer, W. Dürre und Dürreperioden 1934. 1937. 23 p. incl. tables, diagrs. 6 plates (1 fold.).

v. 3, no. 10. Krügler, F. Nächtliche Wärmehaushaltsmessungen an der Oberfläche einer grasbewachsenen Ebene. 1937. 14 p. tables, diagrs.

v. 4, no. 1. Büdel, Auguste. Untersuchung der Wärmeschutzwirkung von Gittern und Pflanzen. Mit 1 Tafel. 1938. 24 p. tables, diagrs.

v. 4, no. 2. Tielsch, Herbert. Beeinflussung der Ultrastrahlung durch das Wetter nach Messungen während der Jahre 1932/1934 zu Königsberg (Pr.) 1938. 21 p. tables, diagrs.

v. 4, no. 4. Ergebnisse phänologischer Beobachtungen im Deutschen Reich im Jahre 1936, bearbeitet vom Phänologischen Dienst des Reichsamtes für Wetterdienst. Mit 8 Karten. 1938. 62 p. tables.

v. 4, no. 5. Foitzik, Leonhard. Über die Lichtdurchlässigkeit der stark getrübten Atmosphäre im sichtbaren Spektralbereich. 1938. 31 p. tables, diagrs.

v. 4, no. 6. Neumann, Ernst. Die Rolle der Zirkulationsleistung und der horizontalen Strömungsdivergenz bei der Westwetterlage vom. 14–16. Februar 1935. Mit 1 Tafel. 1938. 19 p. tables, diagrs.

v. 4, no. 7. Keil, Karl. Ein Beitrag zur Geschichte der Meteorologie in Preuszen. 1938. 17 p. tables.

v. 5, no. 1. Schwerdtfeger, Werner. Über die hohen Wolken. 1938. 33 p. tables, diagrs.

v. 5, no. 2. Leistner, Walter. Das Wattenmeer- und Küstenklima Nordfrieslands und sein Einfluss auf den menschlichen Organismus. 1938. 17 p. diagrs.

Geslin, Henri, & Servy, J.

Pluies, humidité du sol et climat du point de vue agronomique. diagrs. (1 fold.) Ann. agron. n. s. année 7, p. 85-101. Paris. 1937. "Index bibliographique": p. 101.

Hénin, S.

Idées actuelles sur l'eau du sol et ses rapports avec la plante. Diagrs. Ann. agron. n. s. année 6, p. 723-741. Paris. 1936. "Bibliographie": p. 739-741.

Iaranoff, Dimitri.

Essai sur le climat de la Bulgarie pendant le pliocène et le quaternaire. Contribution à l'étude paléoclimatologique de la région méditerranéenne. Sofia. 1936. 28 p. diagr. 23½ cm. (Revue de l'Académie bulgare des sciences. v. LIII. Extrait.)

International telecommunication bureau, Bern.

Tableau indiquant comment sont traités, par les diverses administrations et par les exploitations privées, les radiotélégrammes privés rédigés en langage secret, les radiotélégrammes météorologiques, les radiotélégrammes avec réponse payée, les radiotélégrammes avec collationnement, les radiotélégrammes à remettre: par exprès, par poste, en mains propres, ouverts, les radiotélégrammes multiples, les radiotélégrammes urgents, les radiotélégrammes avec accusé de réception, les avis de service taxés, et les radiotélégrammes de presse originaires des stations mobiles et destinés à la terre ferme, dont l'acceptation est facultative aux termes des Règlements des radiocommunications (révision de Madrid, 1932). [Berne. 1936.] 37 p. 34½ cm. At head of title: Bureau de l'Union international des télécommunications. Service des radiocommunications. Berne. 1936.

Kirde, K.

Temperatur-, Salzgehalt- und Strombeobachtungen des Meeres, 1929-1934. Tartus. 1936. 118 p. tables. 23 cm. (Tartu Ülikooli eesti veekogunde uurimise, Komisjoni Väljaane nr. 25.)

The National geographic society.

National geographic magazine. Cumulative index. Washington, D. C. 25 cm. 1899-1922. * 1923. 207 p.—1899-1936. * 1937. 452 p.

Philippines (Commonwealth). Weather bureau.

Weather observations from ships in the Far East, 1935. By Rev. Miguel Selga, S. J., director of the Weather bureau. Manila. 1936. 31 p. incl. tables. 29 cm.

Sieger, Fritz.

Das Klima des Brocken, unter besonderer Berücksichtigung homogener Luftmassen. Hamburg. 1936. 67 p. tables, diagrs. 23 cm. (Inaugural-dissertation . . . Friedrich-Welhelm-Universität zu Berlin.)

Spain. Sociedad española de meteorología.

Anales. v. 1—1927—Madrid. [1927- 25 cm.

U. S. Information service.

Libraries of the United States government in Washington, D. C. Wash., D. C. 1936. 12 p. 26½ cm.

[U. S. Weather bureau. San Francisco station.]

Official U. S. Weather bureau record of highest and lowest temperatures ever observed in San Francisco, during period January 1875 to June 1934, inclusive. [1934]. 8 p. tables. 28 cm. (Manifolded.)

SOLAR OBSERVATIONS

[Meteorological Research Division, EDGAR W. WOOLARD in charge]

SOLAR RADIATION OBSERVATIONS, SEPTEMBER 1938

By IRVING F. HAND

Measurements of solar radiant energy received at the surface of the earth are made at eight stations maintained by the Weather Bureau, and at nine cooperating stations maintained by other institutions. The intensity of the total radiation from sun and sky on a horizontal surface is continuously recorded (from sunrise to sunset) at all these stations by self-registering instruments; pyrheliometric measurements of the intensity of direct solar radiation at normal incidence are made at frequent intervals on clear days at three Weather Bureau stations (Washington, D. C., Madison, Wis., Lincoln, Nebr.) and at the Blue Hill Observatory of Harvard University. Occasional observations of sky polarization are taken at the Weather Bureau stations at Washington and Madison.

The geographic coordinates of the stations, and descriptions of the instrumental equipment, station exposures, and methods of observation, together with summaries of the data, obtained up to the end of 1936, will be found in the MONTHLY WEATHER REVIEW, December 1937, pp. 415 to 441; further descriptions of instruments and methods are given in Weather Bureau Circular Q.

Table 1 contains the measurements of the intensity of direct solar radiation at normal incidence, with means and their departures from normal (means based on less than 3 values are in parenthesis). At Madison and Lincoln the observations are made with the Marvin pyrheliometer; at Washington and Blue Hill they are obtained with a recording thermopile, checked by observations with a Marvin pyrheliometer at Washington and with a Smithsonian silver disk pyrheliometer at Blue Hill. The table also gives vapor pressures at 8 a. m. (75th meridian time) and at noon (local mean solar time).

Table 2 contains the average amounts of radiation received daily on a horizontal surface from both sun and sky during each week, their departures from normal and the accumulated departures since the beginning of the year. The values at most of the stations are obtained from the records of the Eppley pyrheliometer recording on either a microammeter or a potentiometer.

Direct solar radiation intensities averaged above normal for September at Washington and Blue Hill; below normal at Madison. The Lincoln data for September will be included in the October issue of the REVIEW.

Total solar and sky radiation was above normal at Chicago, New York, La Jolla, New Orleans, San Juan, Lincoln, and Fairbanks; and below normal at all other stations for which normals have been computed.

Polarization measurements made on nine days at Madison give a mean of 42.7 percent with a maximum of 62 percent on the 16th. Both of these values are considerably below the corresponding normals for the month. In connection with these data the official in charge at Madison reports: "The second rainiest month on record at Madison, with 10.29 inches. Dense smoke from a peat bog fire at International Falls, Minn., blew in on the night of the 26th, and the sky was smoky until Oct. 4th." Polarization values of 24, 29, and 15 percent on the 28th, 29th, and 30th of September, respectively, show markedly the effect of this smoke upon atmospheric transparency as do also the direct solar readings at Madison with the larger air masses on the 27th, 28th, and 29th.

LATE DATA

Total solar and sky radiation received on a horizontal surface at Miami for the weeks beginning July 30, August 6, and 13, are as follows: 434, 434, and 492, with corresponding departures of −51, −66, and +27. Instrumental defects prevented additional records for September.

TABLE 1.—*Solar radiation intensities during September 1938*

[Gram-calories per minute per square centimeter of normal surface]

WASHINGTON, D. C.

Date	Sun's zenith distance: 8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th. mer. time	Air mass: A. M.					P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Sept. 21	8.81					1.34					7.29
Sept. 22	7.04	0.44	0.63	0.81	1.19	1.44					6.76
Sept. 23	9.14				1.11	1.41	1.05				9.47
Sept. 24	10.59	.65	.73	.88	1.04	1.32					9.83
Sept. 26	7.87	.90	.98	1.08	1.11	1.39	.95				8.48
Sept. 27	11.38				.86						14.10
Means		.66	.78	.92	1.06	1.38	(1.00)				
Departures		−.03	+.02	+.04	+.01	+.06	−.07				

MADISON, WIS.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Sept. 15	9.47		1.11								12.24
Sept. 16	7.87	1.07	1.13	1.24	1.40						8.48
Sept. 21	7.57			1.15	1.33	1.43					7.87
Sept. 22	8.48	.79	.84	.89	1.18	1.45					9.47
Sept. 23	10.59	.82	.96	1.09	1.23	1.45					11.38
Sept. 24	9.14	.78	.93	1.04	1.28	1.54					13.61
Sept. 26	9.83			.94	1.13	1.32					10.59
Sept. 27	6.76			.69	.78						8.81
Sept. 28	6.50	.55	.64	.75	.91	1.29					7.04
Sept. 29	8.18	.36	.44	.52	.66						10.59
Means		.73	.86	.92	1.10	1.41					
Departures		−.07	−.03	−.09	−.06	+.01					

*Extrapolated.

TABLE 1.—*Solar radiation intensities during September 1938*—Con.

[Gram-calories per minute per square centimeter of ormal surface]

BLUE HILL, MASS.

Date	Sun's zenith distance: 8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th. mer. time	Air mass: A. M.					P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	ca.	Tl.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Sept. 2	8.6				1.17						8.6
Sept. 3	9.2				1.20	1.29					8.9
Sept. 5	6.3				1.26	1.50	1.25				6.8
Sept. 6	6.3		1.13	1.22	1.31	1.40	1.30				6.1
Sept. 8	5.8	.97	1.08	1.18	1.30	1.44	1.19				5.8
Sept. 9	5.6		1.12	1.21	1.31	1.42	1.21	1.04			6.1
Sept. 10	5.6		1.10	1.17	1.29	1.41	1.25	1.19			6.8
Sept. 11	7.9		1.04	1.15	1.27	1.38	1.12	.89			8.8
Means		(.97)	1.09	1.19	1.26	1.41	1.22	1.04			
Departures		+.15	+.14	+.14	+.10	+.04	+.08	+.08			

LATE DATA—BLUE HILL, MASS.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Aug. 2	16.9			.72	.99	1.33	.92				15.8
Aug. 3	18.2			.61	.84	1.12	.79				18.8
Aug. 8	14.7				.99	1.34					15.8
Aug. 9	13.7			.94	1.18	1.49					15.3
Aug. 10	10.7			1.20	1.35	1.49					10.3
Aug. 12	12.8			1.30	1.44						9.9
Aug. 13	12.3				1.07	1.34	1.10				13.2
Aug. 14	13.7					1.36					15.8
Aug. 16	20.8			1.01	1.11	1.22					21.5
Aug. 23	11.9		1.07	1.16	1.28	1.40					11.9
Aug. 25	10.3					1.38					9.6
Means			(1.07)	.99	1.12	1.35	.94				
Departures			+.15	+.03	+.06	+.07	−.13				

TABLE 2.—*Average daily totals of solar radiation (direct+diffuse) received on a horizontal surface*

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Fresno	Fairbanks	Twin Falls	La Jolla	Miami	New Orleans	Riverside	Blue Hill	San Juan	Friday Harbor	Ithaca	Newport
	Gram-calories per square centimeter																
	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Sept. 3	384	209	464		500	578	190	541	498		355	481	491	509	355	441	555
Sept. 10	256	284	403		275	498	210	472	428		352	446	373	618	488	232	401
Sept. 17	205	288	494	361	217	457	154	410	425	430	493	437	202	481	255	143	207
Sept. 24	317	408	449	400	335	395	154	317	415	330	442	386	386	608	229	325	407
	Departures of daily totals from normals																
Sept. 3	+3	−163	+9		+170	+4	−5	+42	+10		−51	−21	+103	−56	−63	+91	
Sept. 10	−109	−53	−26		−39	−42	0	+16	−72		+14	−18	+14	+53	+110	−79	
Sept. 17	−157	−57	+67	+39	−79	−37	−4	+2	+29	−5	+115	+13	−144	−61	−57	−157	
Sept. 24	−31	+112	+71	+125	+51	−65	+25	−104	+56	−49	+74	−24	+40	+103	−80	+62	
	Accumulated departures since Jan. 1																
	−11,582	−1,995	+86	+7.735	+2,842	−1,904	+4,319	−6,447	−2,625	−5,107	+5,985	−5,992	−2,884	+11,508	+7,308	+1,260	

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, U. S. Navy (Ret.), Superintendent, U. S. Naval Observatory. Data furnished by the U. S. Naval Observatory in cooperation with Harvard and Mount Wilson Observatories. The difference in longitude is measured from the central meridian, positive west. The north latitude is positive. Areas are corrected for foreshortening and are expressed in millionths of the sun's visible hemisphere. The total area for each day includes spots and groups]

Date	Eastern standard time		Mt. Wilson group No.	Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot or group	Area: Total for each day	Spot count	Observatory
1938	*h*	*m*		°	°	°				
Sept. 1	12	42	6095	−73.0	43.2	−14.0	97	------	2	U. S. Naval.
			6094	−72.0	44.2	−19.0	194	------	2	
			6093	−53.0	63.2	+11.5	606	------	26	
			6092	−35.0	81.2	+17.5	48	------	8	
			6090	−28.0	88.2	−15.0	291	------	15	
			6089	−27.0	89.2	−7.0	12	------	2	
			6088	−27.0	89.2	+15.0	61	------	6	
			6084	−19.0	97.2	+13.0	388	------	51	
			6087	−7.0	109.2	−20.5	24	------	5	
			6086	+10.0	126.2	−17.0	24	------	4	
			6078	+14.0	130.2	+29.0	24	1,769	3	
Sept. 2	10	55	6097	−80.5	23.4	+10.4	170	------	2	Do.
			6095	−59.5	44.4	−14.0	48	------	3	
			6094	−59.5	44.4	−19.0	194	------	2	
			6096	−54.0	49.9	+16.0	12	------	2	
			6093	−39.0	64.9	+11.5	776	------	50	
			6090	−13.0	90.9	−15.0	291	------	6	
			6088	−13.0	90.9	+14.0	36	------	6	
			6084	−6.0	97.9	+13.0	388	------	44	
			6087	+5.0	108.9	−21.0	6	------	5	
			6086	+22.0	125.9	−16.0	24	1,945	9	
Sept. 3	9	5	6097	−68.0	23.7	+11.0	169	------	------	Mt. Wilson.
			6094	−56.0	35.7	−26.0	48	------	------	
			6094	−48.0	43.7	−19.5	194	------	------	
			6095	−46.0	45.7	−14.0	24	------	------	
			6093	−26.0	65.7	+11.0	824	------	------	
			6088	−1.0	90.7	+14.0	24	------	------	
			6090	−1.0	90.7	−15.0	267	------	------	
			6084	+6.0	97.7	+13.0	388	------	------	
			6086	+36.0	127.7	−16.0	48	1,926	**	
Sept. 4	11	35	6097	−54.0	23.2	+11.0	121	------	5	Do.
			6094	−38.0	39.2	−23.0	24	------	7	
			6094	−33.0	44.2	−19.5	206	------	------	
			6093	−11.0	66.2	+11.0	776	------	30	
			6090	+13.0	90.2	−15.0	267	------	2	
			6084	+16.0	93.2	+13.0	97	------	32	
			6098	+21.0	98.2	−24.0	6	------	1	
			6084	+30.0	107.2	+11.0	145	------	32	
			6086	+51.0	128.2	−15.5	194	1,836	20	
Sept. 5	11	29	6097	−39.5	24.5	+10.5	170	------	1	U. S. Naval.
			6094	−24.5	39.5	−23.0	18	------	1	
			6094	−19.0	45.0	−20.0	218	------	5	
			6099	−13.0	51.0	−15.0	6	------	2	
			6093	+2.0	66.0	+11.0	776	------	65	
			6090	+25.5	89.5	−15.0	242	------	3	
			6084	+29.0	93.0	+13.0	97	------	4	
			6084	+44.0	108.0	+11.0	145	------	14	
			6086	+65.0	129.0	−15.0	97	1,769	10	
Sept. 6	11	30	6100	−53.0	357.8	−19.0	12	------	2	Mt. Wilson.
			6097	−27.0	23.8	+10.5	145	------	1	
			6094	−5.0	45.8	−19.5	206	------	8	
			6099	−1.0	49.8	−16.0	12	------	3	
			6093	+15.0	65.8	+11.0	1,164	------	71	
			6090	+39.0	89.8	−15.0	291	------	5	
			6084	+41.0	91.8	+13.0	36	------	28	
			6084	+55.0	105.8	+11.0	145	------	------	
			6086	+77.0	127.8	−14.0	145	2,156	7	
Sept. 7	11	2	6101	−85.0	312.8	+11.0	6	------	2	U. S. Naval.
			6097	−13.0	24.8	+10.5	145	------	5	
			6094	+7.0	44.8	−20.0	194	------	2	
			6093	+29.0	66.8	+10.5	1067	------	118	
			6090	+51.0	88.8	−16.0	291	------	6	
			6084	+54.0	91.8	+13.0	6	------	4	
			6084	+68.0	105.8	+12.0	36	1,745	12	
Sept. 8	13	37	6101	−70.0	313.2	+11.0	73	------	8	Do.
			6097	+1.0	24.2	+10.5	97	------	3	
			6094	+21.0	44.2	−19.5	194	------	2	
			6093	+44.0	67.2	+10.5	873	------	5	
			6090	+65.0	88.2	−15.0	242	1,479	4	
Sept. 9	11	9	6101	−59.0	312.4	+11.0	121	------	11	Do.
			6102	−58.0	313.4	+18.0	6	------	5	
			6097	+13.5	24.9	+10.5	97	------	2	
			6094	+32.0	43.4	−19.5	242	------	12	
			6093	+49.0	60.4	+13.0	12	------	38	
			6093	+58.0	69.4	+12.0	776	------	8	
			6090	+78.0	89.4	−14.5	194	1,448	2	
Sept. 10	11	11	6104	−80.0	278.1	+10.0	97	------	2	Do.
			6101	−47.0	311.1	+11.0	97	------	8	
			6102	−45.0	313.1	+18.0	48	------	6	
			6097	+27.5	25.6	+10.0	73	------	2	
			6094	+45.0	43.1	−20.0	145	------	10	
			6103	+54.0	52.1	+17.0	12	------	4	
			6093	+71.0	69.1	+11.0	727	1,199	17	

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard time		Mt. Wilson group No.	Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot or group	Area: Total for each day	Spot count	Observatory
1938	*h*	*m*		°	°	°				
Sept. 11	11	50	6104	−68.5	276.1	+9.0	145	------	9	Mt. Wilson.
			6101	−31.0	313.6	+11.0	145	------	10	
			6102	−29.0	315.6	+18.0	61	------	4	
			6097	+40.0	24.6	+10.0	61	------	2	
			6094	+59.0	43.6	−20.0	242	------	5	
			6103	+67.0	51.6	+18.0	24	------	3	
			6093	+83.0	67.6	+10.5	485	1,163	7	
Sept. 12	13	55	6104	−54.5	275.7	+8.5	145	------	10	U. S. Naval.
			6101	−18.0	312.2	+11.0	121	------	12	
			6097	+54.0	24.2	+10.0	48	------	2	
			6094	+72.0	42.2	−19.0	145	459	1	
Sept. 13	13	4	6104	−41.0	276.5	+8.5	145	------	20	Do.
			6101	−5.0	312.5	+10.0	121	------	18	
			6097	+67.0	24.5	+10.0	48	314	3	
Sept. 15	11	25	6105	−79.0	213.0	+22.5	533	------	9	Do.
			6104	−15.0	277.0	+8.5	242	------	40	
			6101	+21.0	313.0	+11.0	73	------	13	
			6106	+41.0	333.0	+18.0	12	860	2	
Sept. 16	11	57	6105	−66.0	212.5	+22.5	364	------	14	Do.
			6104	−1.0	277.5	+8.5	388	------	28	
			6101	+33.0	311.5	+12.0	24	------	9	
			6106	+54.0	332.5	+17.0	48	824	8	
Sept. 18	18	47	6105	−32.0	216.4	+21.0	194	------	9	Mt. Wilson.
			6104	+33.0	281.4	+8.0	291	------	14	
			6101	+65.0	313.4	+14.0	24	509	2	
Sept. 19	11	56	6111	−81.0	157.9	−11.0	388	------	3	Do.
			6110	−69.0	169.9	−25.0	12	------	1	
			6109	−63.0	175.9	+24.0	12	------	4	
			6105	−22.0	216.9	+21.0	194	------	24	
			*	+18.0	256.9	−3.5	6	------	------	
			6108	+37.0	275.9	+19.0	6	------	3	
			6104	+43.0	281.9	+8.0	291	------	13	
			6107	+63.0	301.9	+15.0	12	------	2	
			6101	+74.0	312.9	+12.0	36	957	5	
Sept. 20	12	28	6112	−88.0	137.4	−12.0	97	------	1	Do.
			6111	66.0	159.4	−11.5	727	------	9	
			6110	−55.0	170.4	−25.0	12	------	1	
			6105	−7.0	218.4	+21.0	170	------	19	
			6108	+51.0	276.4	+21.0	6	------	2	
			6104	+57.0	282.4	+7.5	509	------	4	
			6107	+77.0	302.4	+15.0	97	1,618	4	
Sept. 21	11	51	6116	−83.0	129.6	−13.0	291	------	4	U. S. Naval.
			6112	−74.0	138.6	−12.0	291	------	4	
			6111	−52.5	160.1	−11.5	630	------	18	
			6114	−28.5	184.1	+5.0	6	------	3	
			6113	−11.0	201.6	+15.5	6	------	4	
			6105	+5.0	217.6	+21.0	121	------	15	
			6104	+70.0	282.6	+6.0	291	1,636	2	
Sept. 22	12	58	6116	−70.0	128.7	−13.0	921	------	15	Do.
			6112	−57.0	141.7	−12.0	339	------	7	
			6111	−37.0	161.7	−10.5	630	------	12	
			6105	+18.0	216.7	+21.0	194	------	9	
			6104	+81.0	279.7	+5.0	145	2,229	2	
Sept. 23	11	0	6118	−86.0	100.6	+11.0	145	------	3	Do.
			6116	−58.5	128.1	−13.0	1,454	------	50	
			6112	−46.0	140.6	−11.0	388	------	30	
			6111	−26.0	160.6	−10.5	679	------	32	
			6115	−16.0	170.6	−12.0	6	------	2	
			6105	+31.5	218.1	+22.0	73	2,745	8	
Sept. 24	11	40	6121	−74.0	99.1	+14.0	36	------	11	Do.
			6118	−72.0	101.1	+12.0	121	------	5	
			6117	−49.0	124.1	+30.0	12	------	4	
			6116	−44.0	129.1	−13.0	1,212	------	68	
			6112	−31.0	142.1	−11.0	412	------	10	
			6120	−19.0	154.1	+15.0	12	------	2	
			6111	−12.0	161.1	−10.5	582	------	48	
			6119	−9.0	164.1	+12.0	36	------	9	
			6105	+46.0	211.1	+22.0	97	2,520	4	
Sept. 25	9	42	6125	−78.0	83.0	+13.0	12	------	2	Mt. Wilson.
			6122	−76.0	85.0	−12.0	97	------	1	
			6121	−62.0	99.0	+14.0	24	------	6	
			6118	−59.0	102.0	+13.0	121	------	4	
			6117	−38.0	123.0	+30.5	61	------	9	
			6116	−30.0	131.0	−13.0	1,212	------	64	
			6123	−23.0	138.0	+18.0	73	------	6	
			6112	−20.0	141.0	−11.0	388	------	5	
			6120	−6.0	155.0	+15.0	16	------	1	
			6111	+1.0	162.0	−10.0	582	------	23	
			6119	+2.5	163.5	+12.0	97	------	16	
			6105	+60.0	221.0	+21.0	73	2,756	2	
Sept. 26	11	9	6125	−64.0	83.0	+13.0	12	------	2	U. S. Naval.
			6122	−60.0	87.0	−12.0	61	------	1	
			6124	−60.0	87.0	+32.0	18	------	4	
			6121	−47.5	99.5	+14.5	48	------	14	
			6118	−45.0	102.0	+13.0	73	------	5	
			6117	−21.0	126.0	+30.0	24	------	2	
			6116	−17.0	130.0	−13.0	921	------	55	

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard time	Mt. Wilson group No.	Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot or group	Area: Total for each day	Spot count	Observatory
1938	h m		°	°	°				
Sept. 26	11 9	6123	−9.0	138.0	+17.0	242		23	U. S. Naval.
		6112	−7.0	140.0	−11.0	388		9	
		6111	+14.0	161.0	−10.5	388		20	
		6119	+15.0	162.0	+12.0	194		11	
		6105	+71.0	218.0	+21.0	61	2,430	2	
27	11 24	6127	−70.0	63.6	−9.0	73		6	Do.
		6122	−46.0	87.6	−12.0	24		2	
		*	−46.0	87.6	+35.0	12		2	
		6121	−37.0	96.6	+16.0	48		14	
		6121	−29.0	104.6	+15.0	73		12	
		*	−30.0	103.6	−24.0	16		2	
		6117	−9.0	124.6	+31.0	36		7	
		6116	−3.0	130.6	−12.0	485		75	
		6123	+5.0	138.6	+18.0	315		35	
		6112	+7.0	140.6	−11.0	388		8	
		6111	+27.0	160.6	−9.5	436		17	
		6119	+29.5	163.1	+12.0	97		14	
		6105	+85.0	218.6	+21.0	97	2,100	1	
28	11 3	6131	−88.0	32.6	−17.5	97		1	Do.
		6127	−57.0	63.6	−9.0	61		5	
		6122	−34.0	86.6	−13.0	36		3	
		6122	−33.0	87.6	−17.0	16		7	
		6121	−17.0	103.6	+14.0	121		27	
		6117	−1.0	119.6	+31.0	12		2	
		6116	+10.0	130.6	−13.0	533		65	
		6123	+18.0	138.6	+18.0	339		36	
		6112	+19.5	140.1	−11.0	388		6	
		6111	+41.0	161.6	−10.0	485		18	
		6119	+42.0	162.6	+13.0	36	2,124	9	
30	9 22	6131	−57.0	38.2	−17.0	109		1	Mt. Wilson.
		6130	−56.0	39.2	+21.0	194		16	
		6127	−30.0	65.2	−9.0	48		9	
		6125	−22.0	73.2	+13.0	48		30	
		6129	−21.0	74.2	+9.0	36		5	
		6122	−9.0	86.2	−13.0	48		1	
		6121	+7.0	102.2	+14.0	291		47	
		6116	+37.0	132.2	−13.0	218		24	
		6123	+43.0	138.2	+17.0	194		26	
		6112	+46.0	141.2	−12.0	485		6	
		6111	+69.0	164.2	−11.0	436		9	
		6128	+73.0	168.2	+15.0	73	2,180	1	

Mean daily area for 27 days=1,655.
*=not numbered.
** Total spot count for day=110.

PROVISIONAL SUNSPOT RELATIVE NUMBERS FOR SEPTEMBER 1938

[Dependent alone on observations at Zurich, Switzerland]

[Data furnished through the courtesy of Prof. W. Brunner, Eidgen. Sternwarte, Zurich, Switzerland]

September 1938	Relative numbers	September 1938	Relative numbers	September 1938	Relative numbers
1	*d* 106	11	*d* 67	21	*ad* 56
2	*ad* 124	12	59	22	70
3	*a* 101	13	44	23	86
4	107	14	48	24	*d* 97
5	*b* 120	15	*d* 44	25	*MMacc* 131
6	136	16	*a* 47	26	150
7	*a* 106	17	46	27	*ab* 143
8	*a* 88	18	65	28	137
9	74	19	*d* 55	29	*a* 125
10	56	20	57	30	131

Mean, 30 days=89.0.

		h m h m
Sept. 8.	Middle large, bright chromospheric eruption	11 00–11 15, W.
21.	Middle large, bright chromospheric eruption	6 56– 7 14, E.
22.	Middle large, bright chromospheric eruption	13 31–13 50, E.
23.	Middle large, bright chromospheric eruption	15 45–16 20, E.
25.	Middle large, bright chromospheric eruption	9 00– 9 15, E.
26.	Middle large, bright chromospheric eruption	8 43– 9 03, M.

NOTE.—The complete list of eruptions observed at the different stations is being regularly published in our "Bulletin for Character Figures of Solar Phenomena." No. 43, containing the observations of the eruptions in July, August, and September 1938, will not be ready until January 1939.—*W. Brunner.*

a=Passage of an average-sized group through the central meridian.
b=Passage of a large group or spot through the central meridian.
c=New formation of a group developing into a middle-sized or large center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central circle zone.
d=Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[Aerological Division, D. M. LITTLE in charge]

By B. FRANCIS DASHIELL

During the month of September 1938 a total of 307 radiometeorograph and 208 airplane observations were made from 18 systematically-located stations in the United States. The mean free-air data based on these observations are given in tables 1 and 1a, and they include the basic meteorological elements of pressure (P), temperature (C), and relative humidity (R. H.), recorded at certain standard geometric heights. All the stations listed in table 1a made a total of 146 observations at a height of 16 kilometers, while at four of these stations, 27 observations were continued to 22 kilometers.

These "means" are omitted whenever less than 15 observations are made at the surface and less than 5 at a standard height, but 15 observations are required for those levels that fall within the limits of the monthly vertical range of the tropopause. The method used for computing these means has been described in "Aerological Observations," appearing in the January 1938 issue of the MONTHLY WEATHER REVIEW.

Chart I, published elsewhere in this REVIEW, shows that the mean *surface* temperature (° F.) for September was warmer than normal over all portions of the country, except in the Northeast and a few sections of the South and Southwest. Over the northern Rocky Mountain region, and from the lower Missouri Valley and central Plains States northward, the current month was from 4° to 10° warmer than normal, while the far Western States experienced a departure as high as 4° above the normal. But, to the East and Northeast, from the western Great Lakes region and northern middle Atlantic States, the month showed moderate below-normal departures from the mean surface temperatures. For the country, as a whole, the temperature remained above the normal as was the case in the preceding months of July and August.

The mean *free-air* temperature (° C.) recorded *above* the surface over the country was seasonally lower in September than during the preceding month of August. But over the far Northwest, at Seattle and Spokane, Wash., higher mean temperatures prevailed in September at all levels from 0.5 to 5 kilometers, inclusive. Over Seattle, Wash., the September means were higher than in August by 1.7°, 4.3°, 4.1°, 3.4°, 2.8°, 2.6°, and 2.5° C., at 0.5, 1, 1.5, 2, 2.5, 3, and 4 kilometers, respectively. The free-air temperature was lower in September than in July at all stations, with the exception of San Diego, Calif., at 0.5 and 1 kilometer, where a difference of 3.9° occurred at 0.5 kilometer. Temperatures during the current month were approximately the same as recorded in September 1937 in the lower levels, but at the higher elevations the mean temperatures exceeded those recorded in 1937 over the Rocky

Mountain region. They were lower generally, however, over most portions of the East and South.

The highest free-air mean temperatures for September in the United States in the different levels were recorded at Pensacola, Fla. (21.6° C.) at 0.5 kilometer, and at San Diego, Calif. (23.4°, 21.6°, 18.8°, 15.0°, 11.2°, 3.6°, and −2.8° C.) at 1, 1.5, 2, 2.5, 3, 4, and 5 kilometers, respectively. The lowest free-air temperatures for all levels occurred at Sault Ste. Marie, Mich., during September. Over the United States a maximum temperature of 23.4° C. occurred at 1 kilometer at San Diego, Calif., and a minimum of −10.7° C. was recorded over Sault Ste. Marie, Mich., at 5 kilometers.

Above 5 kilometers, in the high altitudes reached by radiometeorographs (table 1a), the lowest mean temperature of the month (−66.9° C.) was recorded at 17 kilometers over Oklahoma City, Okla. But over the more northerly stations of Fargo, N. Dak., and Sault Ste. Marie, Mich., slightly higher temperatures (−63.2° C. and −59.9° C.) were recorded at 16 and 17 kilometers, respectively. The lowest temperatures found in the high altitudes during September, over all stations using radiometeorographs, occurred approximately along the 17-kilometer level. A gradual increase in mean temperature was then noted, from 17 kilometers up to the maximum elevation reached (23 kilometers), and was as much as 9° C. increase over Nashville, Tenn.

The pressure data given in tables 1 and 1a, when entered on isobaric charts for all levels up to and including 5 kilometers, showed that during September a statistical low pressure area persisted above the northern Great Lakes region with its center over Sault Ste. Marie, Mich. Another, but smaller, area of low pressure was noted in the lower levels over the southern Pacific coast region. Pressure generally was high throughout the southern States and Rocky Mountain region above 2 kilometers. During the current month mean free-air pressures were lower, except in the far Northwest, than those which were recorded in the preceding month of August. The statistical center of low pressure that existed over Sault Ste. Marie, Mich., at all levels below 5 kilometers, also extended upward through all high-altitude levels to 19 kilometers, and then spread out east and west to include the region over Fargo, N. Dak., up to 22 kilometers.

High relative humidity occurred over the eastern half of the United States during September up to 4 kilometers, and over the Pacific Coast at 0.5 kilometer. The highest mean humidity (86 percent) was recorded over Sault Ste. Marie, Mich., at 0.5 kilometer. High humidities elsewhere were reported over Washington, D. C., at 1, 1.5, 2, 2.5, and 3 kilometers, and over El Paso, Tex., at 4 and 5 kilometers. Low humidity prevailed over the western States and the Pacific Slope at all levels above 1 kilometer, and over New England and the immediate coast along the middle Atlantic States at 2, 2.5, 3, and 4 kilometers. There was little difference between the humidities reported during September and the preceding month of August, except over the far West, but the current month had higher humidities at all levels than during the corresponding month of 1937, and particularly so over the Eastern half of the country above 1.5 kilometer.

Resultant winds in the free atmosphere, based on pilot-balloon observations made at 26 stations near 5 a. m. (75th meridian time), are given in table 2. The resultant winds during the month of September diverged more than usual from the normal directions at many stations over the United States at all levels, but the departures in resultant velocity from normal were not so outstanding, except high over the northern Rocky Mountain region.

Unusual departures in resultant directions from the normal in each level occurred at several scattered stations during September. On the surface, at Fargo, N. Dak., the monthly resultant was 39°; at 0.5 kilometer, over Fargo, N. Dak., the resultant was 340°; at 1 kilometer, over Atlanta, Ga., it was 296°; at 1.5 kilometers, over Seattle, Wash., it was 180°; at 2 kilometers, over Oakland, Calif., the resultant was 184°; at 2.5 kilometers, over Seattle, Wash., it was 209°; at 3 kilometers, over Pensacola, Fla., it was 301°; at 4 kilometers, over Albuquerque, N. Mex., it was 165°; and at 5 kilometers, over Key West, Fla., the monthly resultant wind direction was 302°; as compared with the normal directions of: 183°, 210°, 98°, 288°, 297°, 295°, 49°, 261°, and 87°, respectively.

Large departures of resultant direction from the normal were noted at Seattle, Wash.; Atlanta, Ga.; Fargo, N. Dak.; Pensacola, Fla.; Oakland, Calif.; Spokane, Wash.; Sault Ste. Marie, Mich.; Medford, Ore.; Key West, Fla.; and Oklahoma City, Okla. The stations reporting the least departures at all levels were: Boston, Mass.; Detroit, Mich.; and Washington, D. C. At Salt Lake City, Utah; Spokane, Wash., Oakland, Calif., Pensacola, Fla., and Atlanta, Ga.; the winds departed from normal at all levels by rotating in a counterclockwise direction, while at Cincinnati, O., Nashville, Tenn., Omaha, Nebr., and Chicago, Ill., the departures were opposite, when considered as being rotated in a clockwise direction away from the normal. Wind directions for September varied from the normal more than during any of the preceding summer months of June, July, and August 1938.

Seattle, Wash., showed the most outstanding departures from normal direction in September. The differences between the monthly resultants and their normal directions were: 100°—with the monthly direction departing in a clockwise rotation from its normal; 95°—when rotated counterclockwise; 108°—counterclockwise; 82°—counterclockwise; 86°—counterclockwise; and 49°—counterclockwise; at 0.5, 1, 1.5, 2, 2.5, and 3 kilometers, respectively. At all levels above 1 kilometer the resultant directions for September at Seattle, Wash., had southwesterly components. And, as was previously noted, Seattle experienced unusual warmth in the upper air. Fargo, N. Dak., and Sault Ste. Marie, Mich., showed strong clockwise departures from normal above the surface, with the winds for September becoming more northwesterly than usual. These two stations reported low free-air temperatures at all levels, as previously indicated. In the South, over Atlanta, Ga., the departures in direction were unusual in the lower levels, with the current winds being westerly instead of easterly. And, at Pensacola, Fla., the September wind directions were 27°, 49°, 50°, 36°, 24°, 345°, 301°, and 305°, as compared to the normal directions of 35°, 82°, 103°, 109°, 94°, 13°, 49°, and 347°, respectively. Key West, Fla., however, indicated only slight departures from its normal easterly directions at all levels below 2.5 kilometers, but with the current resultant directions backing gradually away from their normal directions to as much as 302° at 5 kilometers, as compared to its normal of 87°.

The distribution of resultant wind directions over the country at all levels during September in the four quadrants of the compass also showed the existence of irregular upper-air conditions. At the surface most of the winds had normal northerly components—36 percent falling in the northwest quadrant, and 32 percent in the northeast. But, above 0.5 kilometer, where only 5 percent of the winds were northeasterly and 55 percent northwesterly, a gradual increase in northeasterly winds was noted up to 4 kilometers. Here it was found that 15

percent of the winds fell within the northeast quadrant, 50 percent were northwesterly, 20 percent southwesterly, and 10 percent southeasterly. At 0.5 kilometer, 20 percent of the winds had easterly components, and 80 percent showed westerly. This continued up to 4 kilometers, where 26 percent of the resultant directions were from an easterly point, but at 5 kilometers only 9 percent were easterly while 91 percent had westerly components.

Resultant wind velocities remained nearly normal, as a rule, at all levels over most of the country. The greatest negative departures from normal (5.1 m. p. s.) occurred over Billings, Mont., at 5 kilometers, and the greatest positive departure (3.2 m. p. s.) was noted at 3 kilometers over Oakland, Calif. Large, but nearly equal, departures in velocity were recorded above Cheyenne, Wyo., at 3, 4, and 5 kilometers. Negative departures from normal velocities for September were recorded over the northern and central States at all levels up to 2 kilometers, and also over the Rocky Mountains and far Northwest at 2.5 and 3 kilometers. At 4 kilometers, negative, or less-than-normal, departures in velocity included the entire Pacific coast, except southern California; and all of the United States, with the exception of a belt across the extreme South at 5 kilometers. At all levels, positive departures in velocity were confined generally to the South and East, and along the entire Pacific coast in the levels below 2.5 kilometers. The resultant velocity conditions over the country in September were quite the opposite to those which existed during the preceding month of August, when nearly all resultants indicated a decided trend toward positive departures from the monthly normal.

TABLE 1.—*Mean free-air barometric pressures (P) in mb., temperatures (T) in ° C., and relative humidities (R. H.) in percent obtained by airplanes during September 1938*

Stations and elevations in meters above sea level	Altitude (meters) m. s. l.													
	Surface				500			1,000			1,500			
	Number of obs.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	
Billings, Mont. (1,090 m)	30	894	15.5	55	----	----	----	----	----	----	853	18.9	44	
Cheyenne, Wyo. (1,873 m)	29	816	10.9	78	----	----	----	----	----	----	----	----	----	
Chicago, Ill. (187 m)	30	994	15.9	82	957	16.8	75	904	15.1	71	852	12.6	74	
Coco Solo, C. Z.[1] (15 m)	27	1,008	24.8	93	955	24.0	83	902	21.3	82	850	18.6	80	
El Paso, Tex. (1,193 m)	30	884	17.7	69	----	----	----	----	----	----	854	19.6	54	
Lakehurst, N. J.[1] (39 m)	25	1,012	13.3	91	957	15.4	69	903	12.7	68	851	10.2	71	
Norfolk, Va.[1] (10 m)	21	1,017	19.7	89	962	19.5	72	907	17.0	69	855	14.5	67	
Pearl Harbor, T. H.[1] (6 m)	30	1,014	23.0	82	959	22.3	73	904	19.1	77	853	16.0	76	
Pensacola, Fla.[1] (13 m)	30	1,016	20.5	88	961	21.6	68	907	18.6	75	855	15.6	74	
St. Thomas, V. I.[1] (8 m)	30	1,015	28.0	76	960	24.6	86	906	21.6	87	856	19.2	78	
Salt Lake City, Utah (1,288 m)	30	873	15.7	53	----	----	----	----	----	----	852	20.6	40	
San Diego, Calif.[1] (10 m)	29	1,012	18.8	86	956	19.1	80	902	23.4	51	851	21.6	42	
Seattle, Wash.[1] (10 m)	23	1,017	17.2	76	960	15.1	78	906	16.4	54	853	14.3	48	
Spokane, Wash. (597 m)	30	946	13.8	65	----	----	----	903	19.6	46	852	17.2	44	

Stations and elevations in meters above sea level	2,000			2,500			3,000			4,000			5,000		
	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.
Billings, Mont. (1,090 m)	804	15.8	43	758	12.0	46	714	8.2	47	631	0.8	48	557	−6.2	49
Cheyenne, Wyo. (1,873 m)	804	14.3	63	758	13.4	55	714	10.1	55	632	2.1	50	558	−6.0	62
Chicago, Ill. (187 m)	802	9.7	73	755	7.2	66	710	4.4	62	628	−1.4	55	553	−7.3	48
Coco Solo, C. Z.[1] (15 m)	802	15.9	79	756	13.7	71	712	11.0	65	631	5.0	70	557	−0.7	73
El Paso, Tex. (1,193 m)	805	17.2	53	758	13.5	57	715	9.4	62	632	1.9	65	558	−4.7	60
Lakehurst, N. J.[1] (39 m)	801	8.8	58	754	6.1	53	709	3.8	45	625	−2.0	41	----	----	----
Norfolk, Va.[1] (10 m)	805	11.9	66	759	9.4	62	714	7.0	58	632	1.8	49	557	−4.2	46
Pearl Harbor, T. H.[1] (6 m)	804	13.5	70	757	12.8	51	713	11.9	36	632	8.2	25	----	----	----
Pensacola, Fla.[1] (13 m)	806	12.9	67	759	10.3	59	715	7.7	56	632	2.5	50	558	−3.2	46
St. Thomas, V. I.[1] (8 m)	807	16.4	77	761	13.8	74	717	11.5	66	636	6.2	55	562	0.1	48
Salt Lake City, Utah (1,288 m)	804	18.2	38	758	14.9	39	714	11.0	43	633	3.3	51	558	−4.3	60
San Diego, Calif.[1] (10 m)	803	18.8	37	757	15.0	36	713	11.2	36	632	3.6	37	558	−2.8	33
Seattle, Wash.[1] (10 m)	804	11.7	46	756	9.1	41	712	6.5	36	629	0.4	33	----	----	----
Spokane, Wash. (597 m)	803	13.5	48	757	9.6	52	712	5.9	53	629	−0.6	51	554	−6.9	48

[1] Navy.

Observations taken about 4 a. m. 75th meridian time, except by Navy stations along the Pacific coast and Hawaii where they are taken at dawn.
NOTE.—None of the means included in this table are based on less than 15 surface or 5 standard-level observations.

TABLE 1a.—*Mean free-air barometric pressures (P) in mb., temperatures (T) in °C., and relative humidities (R. H.) in percent obtained by radiometeorographs during September 1938*

Altitude (meters) m. s. l.	Stations and elevations in meters above sea level															
	Fargo, N. Dak. (274 m)				Nashville, Tenn. (180 m)				Oakland, Calif. (2m)				Oklahoma City, Okla. (391 m)			
	Number of obs.	P	T	R. H.	Number of obs.	P	T	R. H.	Number of obs.	P	T	R. H.	Number of obs.	P	T	R. H.
Surface	30	984	11.3	78	30	995	17.6	89	30	1,014	14.1	88	30	971	19.0	71
500	30	958	15.5	72	30	959	19.0	76	30	957	16.2	73	30	959	20.2	67
1,000	30	903	15.1	63	30	905	18.0	68	30	902	18.4	54	30	905	20.9	57
1,500	30	851	12.7	60	30	853	14.8	69	30	851	16.6	40	30	854	18.2	56
2,000	30	802	9.9	59	30	804	11.6	69	29	802	13.9	44	30	805	15.1	57
2,500	30	754	7.2	59	30	757	8.9	66	29	756	10.8	40	30	759	11.9	58
3,000	30	710	4.8	55	30	713	6.0	62	29	711	7.9	38	30	715	8.3	57
4,000	30	627	−1.1	50	30	630	0.2	56	29	629	1.8	36	30	632	2.1	54
5,000	30	553	−7.1	46	30	556	−5.8	52	29	555	−5.1	34	30	558	−4.3	53
6,000	30	485	−13.5	45	30	489	−11.5	46	29	488	−11.8	33	30	490	−10.2	49
7,000	30	425	−20.6	44	30	428	−18.1	43	29	427	−19.0	33	30	430	−17.1	46
8,000	30	371	−27.8	44	30	374	−24.9	42	29	373	−26.3	32	30	376	−24.2	44
9,000	30	321	−35.3	43	30	325	−31.9	40	29	324	−33.9	32	28	327	−31.3	43
10,000	30	278	−42.8	----	30	282	−38.5	37	29	280	−41.2	32	27	283	−38.6	42
11,000	30	239	−49.6	----	30	243	−44.8	----	28	242	−47.9	----	27	244	−45.5	----
12,000	29	204	−55.4	----	30	209	−50.4	----	28	207	−53.2	----	26	210	−51.4	----
13,000	29	175	−59.1	----	30	179	−55.3	----	28	177	−56.3	----	25	180	−55.9	----
14,000	29	149	−61.1	----	30	153	−59.0	----	28	151	−58.9	----	25	154	−60.0	----
15,000	28	126	−62.4	----	30	130	−61.7	----	26	129	−61.3	----	21	130	−63.1	----
16,000	28	108	−63.2	----	30	111	−63.6	----	25	110	−62.4	----	20	111	−66.1	----
17,000	25	91	−63.1	----	29	94	−64.3	----	24	93	−63.0	----	19	93	−66.9	----
18,000	21	77	−63.0	----	26	80	−64.1	----	23	79	−62.8	----	18	79	−66.4	----
19,000	17	66	−62.1	----	21	68	−62.9	----	21	67	−61.8	----	15	67	−64.9	----
20,000	15	56	−61.4	----	18	57	−61.1	----	19	57	−60.7	----	11	56	−63.5	----
21,000	9	48	−60.7	----	16	49	−59.0	----	11	49	−59.5	----	10	48	−61.4	----
22,000	5	41	−59.8	----	9	42	−57.1	----	8	42	−58.4	----	5	41	−59.1	----
23,000	----	----	----	----	7	36	−55.4	----	----	----	----	----	----	----	----	----

Altitude (meters) m. s. l.	Omaha, Nebr. (300 m)				Sault Ste. Marie, Mich. (221 m)				Washington, D. C. (13 m) [1]			
	Number of obs.	P	T	R. H.	Number of obs.	P	T	R. H.	Number of obs.	P	T	R. H.
Surface	30	981	16.3	85	29	990	9.4	92	29	1,016	16.8	88
500	30	959	17.9	72	29	957	10.1	86	28	960	16.3	79
1,000	30	905	18.2	60	29	901	8.6	77	28	905	14.2	77
1,500	30	854	15.8	58	29	848	7.0	69	28	853	12.0	75
2,000	30	804	12.5	58	29	798	5.2	63	28	804	9.8	73
2,500	30	757	9.7	57	29	750	2.8	61	28	756	7.5	69
3,000	30	713	6.9	55	28	705	0.3	60	28	712	5.1	66
4,000	30	630	−0.1	52	28	622	−4.8	54	28	629	−0.1	60
5,000	28	556	−7.1	53	27	547	−10.7	52	28	554	−5.7	54
6,000	28	488	−12.5	48	27	480	−17.0	49	28	487	−11.8	50
7,000	28	427	−19.3	47	27	419	−23.5	47	28	427	−17.9	50
8,000	27	374	−26.2	46	26	364	−30.4	46	27	374	−24.3	49
9,000	26	324	−33.0	45	25	316	−37.3	45	26	325	−31.3	48
10,000	26	281	−40.1	44	25	273	−43.5	----	25	282	−38.1	----
11,000	26	242	−47.2	----	25	235	−48.8	----	25	243	−45.1	----
12,000	26	208	−53.1	----	25	202	−52.1	----	24	209	−51.9	----
13,000	26	177	−57.7	----	25	173	−54.6	----	22	179	−57.5	----
14,000	24	151	−59.8	----	25	147	−57.0	----	20	153	−62.0	----
15,000	23	128	−61.8	----	23	126	−58.4	----	13	130	−64.1	----
16,000	20	109	−63.7	----	18	107	−59.4	----	5	110	−64.5	----
17,000	18	92	−64.2	----	16	91	−59.9	----	----	----	----	----
18,000	18	78	−63.7	----	14	78	−59.2	----	----	----	----	----
19,000	11	66	−62.4	----	7	66	−58.1	----	----	----	----	----
20,000	----	----	----	----	----	----	----	----	----	----	----	----
21,000	----	----	----	----	----	----	----	----	----	----	----	----
22,000	----	----	----	----	----	----	----	----	----	----	----	----
23,000	----	----	----	----	----	----	----	----	----	----	----	----

Observations taken about 4 a. m. 75th meridian time, except by Navy stations along the Pacific coast and Hawaii where they are taken at dawn.

[1] Navy.

NOTE.—None of the means included in this table are based on less than 15 surface or 5 standard-level observations.
Number of observations refers to pressure only as temperature and humidity data are missing for some observations at certain levels also the humidity data are not used in daily observations when the temperature is below −40° C.

106757—38——3

Table 3 shows the maximum wind velocities recorded during September. Below 2.5 kilometers the highest velocity recorded was 33.8 m. p. s. (W.) over Newark, N. J.; between 2.5 and 5 kilometers the greatest was 38.5 m. p. s. (S.) over Winnemucca, Nev.; and above 5 kilometers, a wind speed of 61.0 meters per second (147 miles per hour) from the NNE. was recorded at 8.3 kilometers, over Fargo, N. Dak. At 12.9 kilometers, over Albuquerque, N. Mex., a velocity of 56.0 m. p. s. from the WNW., was observed.

TABLE 2.—*Free-air resultant winds (meters-per second) based on pilot-balloon observations made near 5 a. m. (E. S. T.) during September 1938*

[Wind from N=360°, E=90°, etc.]

Altitude (meters) m. s. l.	Albuquerque, N. Mex. (1,554 m)		Atlanta, Ga. (306 m)		Billings, Mont. (1,095 m)		Boston, Mass. (15 m)		Cheyenne, Wyo. (1,873 m)		Chicago, Ill. (192 m)		Cincinnati, Ohio (157 m)		Detroit, Mich. (204 m)		Fargo, N. Dak. (283 m)		Houston, Tex. (21 m)		Key West, Fla. (11 m)		Medford, Oreg. (410 m)		Nashville, Tenn. (194 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°		°	
Surface	4	1.5	327	1.0	283	1.4	277	1.5	276	3.6	283	0.2	122	0.2	277	1.0	39	0.3	22	0.9	90	2.2	238	0.3	204	0.8
500	------	------	316	1.9	------	------	296	3.3	------	------	305	.6	248	1.9	280	1.6	340	.8	144	2.2	104	3.4	247	.6	237	3.1
1,000	------	------	296	2.5	------	------	296	3.6	------	------	278	2.9	266	5.1	271	3.2	311	3.3	140	2.1	119	3.2	293	1.1	271	3.2
1,500	------	------	290	2.5	287	1.0	291	4.6	------	------	291	4.7	277	5.2	276	5.7	314	4.9	121	2.1	112	3.1	115	.7	270	2.8
2,000	154	.9	278	1.7	246	1.1	293	6.5	273	4.5	294	7.4	276	5.3	292	7.1	319	6.6	74	1.5	107	2.9	169	1.7	283	3.2
2,500	198	2.9	276	2.9	270	2.0	299	7.7	272	3.3	297	7.2	283	5.9	284	7.1	315	6.9	39	2.3	97	2.0	186	3.1	283	3.9
3,000	193	2.3	261	2.9	275	3.3	296	8.6	293	2.9	313	6.1	294	6.8	304	7.0	332	7.1	44	2.9	73	1.7	189	3.7	290	4.2
4,000	165	1.0	266	3.6	281	4.2	285	9.2	319	4.5	------	------	290	6.2	------	------	------	------	32	2.1	71	1.3	195	3.0	276	5.4
5,000	295	.3	228	2.5	300	2.5	------	------	289	4.1	------	------	------	------	------	------	------	------	293	2.2	302	1.6	202	3.0	289	3.4

Altitude (meters) m. s. l.	Newark, N. J. (14 m)		Oakland, Calif. (8 m)		Oklahoma City, Okla. (402 m)		Omaha, Nebr. (306 m)		Pearl Harbor, Territory of Hawaii [1] (68 m)		Pensacola, Fla.[1] (24 m)		St. Louis, Mo. (170 m)		Salt Lake City, Utah (1,292 m)		San Diego, Calif. (15 m)		Sault Ste. Marie, Mich. (198 m)		Seattle, Wash. (14 m)		Spokane, Wash. (603 m)		Washington, D. C. (3 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°		°	
Surface	349	1.3	253	0.1	175	2.1	171	0.4	------	------	27	3.0	277	0.8	145	3.8	18	1.3	1	0.3	138	0.7	79	1.6	328	0.6
500	332	2.1	284	1.8	180	3.1	207	2.2	------	------	49	3.6	267	4.2	------	------	350	4.2	359	.5	336	.2	------	------	320	1.2
1,000	279	3.6	317	2.2	211	4.7	248	4.4	------	------	50	2.4	277	4.1	------	------	344	1.7	320	2.6	202	.5	148	1.3	308	4.1
1,500	272	6.4	233	.6	249	2.6	262	4.8	------	------	36	1.8	288	4.1	154	5.6	228	1.6	324	5.2	180	1.3	192	1.8	290	5.8
2,000	274	7.3	184	1.9	268	2.2	284	4.7	------	------	24	1.0	290	4.1	172	4.8	207	3.2	314	5.6	217	1.7	196	2.0	280	7.0
2,500	283	9.1	170	2.7	294	2.9	291	5.5	------	------	345	.7	303	4.6	187	3.8	188	5.1	318	6.8	209	2.6	211	2.9	270	7.6
3,000	294	7.7	166	4.7	307	3.1	296	5.9	------	------	301	1.4	307	3.5	208	3.5	174	6.9	312	7.4	252	1.5	220	3.3	270	7.8
4,000	------	------	------	------	3	2.8	334	6.6	------	------	305	2.8	289	4.3	213	4.3	180	6.9	299	7.7	------	------	228	4.2	280	6.3
5,000	------	------	------	------	24	.9	349	3.9	------	------	------	------	257	3.4	217	2.9	196	7.1	------	------	------	------	246	4.1	------	------

[1] Navy stations.

TABLE 3.—*Maximum free air wind velocities (m. p. s.), for different sections of the United States, based on pilot balloon observations during September 1938*

Section	Surface to 2,500 meters (m. s. l.)					Between 2,500 and 5,000 meters (m. s. l.)					Above 5,000 meters (m. s. l.)				
	Maximum velocity	Direction	Altitude (m), m. s. l.	Date	Station	Maximum velocity	Direction	Altitude (m), m. s. l.	Date	Station	Maximum velocity	Direction	Altitude (m), m. s. l.	Date	Station
Northeast [1]	33.8	W	820	21	Newark, N. J	34.7	SW	5,000	19	Cleveland, Ohio	39.2	SW	5,560	19	Cleveland, Ohio.
East-Central [2]	26.2	NNE	1,230	21	Richmond, Va	28.8	WSW	3,750	22	Richmond, Va	39.4	WSW	11,190	27	Knoxville, Tenn.
Southeast [3]	21.3	SW	1,180	29	Jacksonville, Fla	29.4	SW	3,580	17	Spartanburg, S. C	29.5	WSW	10,600	24	Charleston, S. C.
North-Central [4]	33.0	NW	2,270	4	Sault Ste. Marie, Mich.	36.8	NW	3,530	4	Sault Ste. Marie, Mich.	61.0	NNE	8,290	18	Fargo, N. Dak.
Central [5]	23.4	NW	1,400	17	Kansas City, Mo	30.6	NW	4,800	18	Wichita, Kans	56.0	N	10,840	19	Omaha, Nebr.
South-Central [6]	29.2	NNW	2,470	18	Oklahoma City, Okla.	27.0	WNW	4,870	19	Vicksburg, Miss	34.0	WNW	11,910	17	Abilene, Tex.
Northwest [7]	20.7	SSW	2,500	20	Portland, Oreg	26.3	SSW	4,780	3	Medford, Oreg	42.4	ESE	12,420	26	Pendleton, Oreg.
West-Central [8]	30.4	S	2,130	18	Winnemucca, Nev	38.5	S	3,040	18	Winnemucca, Nev	57.0	SSW	8,240	28	Reno, Nev.
Southwest [9]	24.9	SSE	2,180	27	Fresno, Calif	34.4	S	3,720	27	Las Vegas, Nev	56.0	WNW	12,920	26	Albuquerque, N. Mex.

[1] Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, and northern Ohio.
[2] Delaware, Maryland, Virginia, West Virginia, southern Ohio, Kentucky, eastern Tennessee, and North Carolina.
[3] South Carolina, Georgia, Florida, and Alabama.
[4] Michigan, Wisconsin, Minnesota, North Dakota, and South Dakota.
[5] Indiana, Illinois, Iowa, Nebraska, Kansas, and Missouri.
[6] Mississippi, Arkansas, Louisiana, Oklahoma, Texas (except El Paso), and western Tennessee.
[7] Montana, Idaho, Washington, and Oregon.
[8] Wyoming, Colorado, Utah, northern Nevada, and northern California.
[9] Southern California, southern Nevada, Arizona, New Mexico, and extreme west Texas.

RIVERS AND FLOODS

[River and Flood Division, MERRILL BERNARD in charge]

By BENNETT SWENSON

The outstanding floods during the month of September 1938 occurred in New England from September 20 to 28. These floods were caused by heavy rains antecedent to, and accompanying, the passage of a hurricane which passed inland over the southern New England coast during the afternoon of September 21. A discussion of the hurricane appears as a special article in this REVIEW. The floods were most severe in Contoocook River, a tributary of the Merrimack, and in the lower Connecticut River. The crest stage at Hartford, Conn., 35.42 feet on September 23, was within 2.1 feet of the highest stage of record in March 1936. A more complete report on these floods will be given in the next issue of the REVIEW.

Severe floods occurred also in some of the tributaries of the Upper Mississippi River, principally in the Chippewa, Black, and Wisconsin Rivers in Wisconsin. Prolonged heavy rains over that area and its vicinity resulted in considerable overflowing. The heavy discharge of the tributaries caused the Mississippi River to pass flood stage from the vicinity of La Crosse, Wis., to Louisiana, Mo. This flood, which was unusual for this time of the year, will be discussed at greater length in the following issue of the REVIEW.

Atlantic Slope drainage.—The heavy rains that produced the New England floods also extended over the Mohawk-Hudson River basin and resulted in floods in these rivers.

The crest stage at Albany, N. Y., was 16.5 feet on September 22, 1.3 feet lower than the crest stage in March 1936 and within 4.8 feet of the greatest flood of record, March 28, 1913.

The mean rainfall for the period September 17–21 of 21 rainfall stations in the Hudson and Mohawk watersheds was 5.57 inches, ranging from 4.08 inches at North Creek to 7.61 inches at Albany, N. Y. The latter is the greatest amount ever recorded at Albany for a period of 5 days since the establishment of the station in 1874.

Considerable damage resulted in the Hudson River Valley from a combination of the wind, heavy rain, and flood. The total is estimated at more than $5,000,000.

The curvature of the tropical disturbance to the northwest, after passing inland, caused heavy rain to spread over western New York on the 21st and 22d, resulting in moderate overflows in the upper reaches of the Delaware and Susquehanna River systems.

An overflow in the lower Neuse River in North Carolina was caused mainly by a heavy flood in the Little River. Stages in the upper Neuse River were low and did not reach bankful stage at Smithfield, N. C., the first gaging station above the mouth of the Little River.

Missouri Basin.—Excessive rain over a period of about 2 hours on the night of September 4, in the vicinity of Hot Springs, S. Dak., resulted in sudden floods in Fall River and Beaver Creek, upper tributaries of the Cheyenne River and located in the southern Black Hills region. The rainfall recorded at Hot Springs between 7 and 9:30 p. m. was 2.10 inches, while it has been estimated that three times as much rain occurred a few miles northeast over Beaver Creek.

Two persons were drowned in a tributary canyon of Beaver Creek and the loss from the Fall River overflow is estimated to be about $25,000.

A moderate flood occurred in the Big Sioux River in Iowa from September 14 to 19. The stage at Akron, Iowa, rose rapidly to 12.1 feet on the 14th and then slightly for 2 days, after which a rise of 3.4 feet occurred on the 17th. The highest stage was 16.3 feet on September 17, 4.3 feet above flood stage, but no damage of consequence resulted.

A rise in the middle Missouri River about September 14 approached but did not exceed bankful stage. At Nebraska City, Nebr., the crest stage was 14.0 feet, flood stage 15 feet.

A 3-day rainfall of high intensity beginning August 31, along the eastern slope of the Rocky Mountains, extending from the Wyoming State line southward to Colorado Springs, Colo., a distance of 150 miles, caused flood damage estimated at more than $500,000. Practically every stream in the foothills region was at or above flood stage; the greatest damage occurred in the vicinities of Morrison and Eldorado Springs, Colo. Six persons were drowned in Bear Creek, near Morrison, and one in Coal Creek, near Louisville, Colo.

Arkansas Basin.—Moderately heavy rains over the upper North Canadian River basin during most of the first week of September resulted in flooding above, but not at, Oklahoma City from September 6 to 16. The South Canadian River reached, but did not exceed flood stage. Practically all of the damage occurred in the Panhandle counties of Oklahoma.

West Gulf of Mexico drainage.—The flood in the lower Rio Grande, which was in progress at the close of August and the beginning of September, is described by the official in charge, Brownsville, Tex., as follows:

> Heavy to torrential rains occurred at and in the vicinity of Monterrey, Mexico, and probably over most of the San Juan and other nearby watersheds on August 28 and 29. The rains resulted from the tropical storm that went inland about 100 miles south of Brownsville, Tex., during the night of August 27–28, causing a rapid and decided rise in the San Juan and probably other smaller streams tributary to the Rio Grande in the section of Rio Grande City, Tex., on August 29 and 30.
>
> These streams emptying into the Rio Grande between Rio Grande City and Roma, Tex., caused a rapid and decided rise in the Rio Grande at Rio Grande City on August 29, and it continued to rise there during the following 2 days until it reached the unusual crest stage of 30.1 feet during the forenoon of August 31. This great volume of water caused stages above flood all along the lower valley, amounting to practically a major flood, but kept under remarkable control by the various flood control levees, flood control outlets, etc., on both the American and Mexican sides of the river. Monetary damages were therefore almost negligible for such a great volume of water. The greatest item of estimated damage was to a few breaks in the main levees and erosion of the river banks near one or two of the large irrigation pumping plants.

The destructive flood[1] that occurred in the Colorado River in Texas from July 22 to August 3, 1938, inundated portions of 12 counties. Six people were reported drowned and the property and crop loss has been estimated at $5,000,000.

The flood was caused by unusually heavy rains over a small area centered over the Brady Creek-San Saba River, a tributary of the Colorado River. The rains were heaviest from July 21 to 23, inclusive, but heavy rains were more or less general from 19th to 24th and rain-

[1] Table of flood stages appears in the MO. WEA. REV., August 1938.

fall was recorded at most stations from July 18 to 25 in that area.

Table 1 shows the daily precipitation at the stations in the Colorado Basin. The precipitation decreased in amount toward the upper and lower portions of the basin, the least rainfall occurring in the lower portion from Wharton, Tex., downstream. In the middle and upper portions rain occurred generally from July 18 to 25, while in the lower portion they began on July 21 and continued to July 25.

At Sloan, Tex., located on the San Saba River near its confluence with the Colorado, rainfall was recorded as follows: 3.70 inches on the 21st, 3.92 on the 22d, and 8.47 on the 23d, with a total of 21.49 inches from July 18 to 25; Eden, Tex., located on Brady Creek, reported 1.58 on the 21st, 1.39 on the 22d, and 6.89 inches on the 23d, with a total of 16.89 inches from the 18th to 25th.

Small streams in the Brady Creek-San Saba River watershed rose rapidly, damaging highways, bridges, and crops. The losses in McCullock and San Saba Counties are estimated at $500,000. However, the greater portion of the flood loss occurred along the main channel of the Colorado River from Austin to Bay City, Tex.

The reservoir formed by Buchanan Dam, located west of the town of Burnet, was well filled, although not to capacity, before excessive rains occurred approximately 50 to 75 miles upstream. To prevent the reservoir overflowing the dam, a number of flood gates were opened. At Marble Falls, first gaging station below the dam, the stage rose from 6.0 feet on July 22 to 25.6 feet on the 23d, to 31.0 feet on the 24th, with a crest of 36.4 feet on the 25th. Hourly gage readings at Austin, Tex., from 3 p. m. July 23 to 8 p. m. July 27 are given in table 2.

No losses occurred at Marble Falls as the river banks are high, but communities along the river including Austin, Bastrop, La Grange, Columbus, Wharton, and Bay City sustained heavy losses. The losses for the section of the river from Austin to the Gulf of Mexico have been estimated at $4,500,000.

Flood warnings were issued for Austin and vicinity on July 23, when the river stage was zero or lower. On July 24, warnings were issued for the lower sections of the river.

Strong southerly winds prevailed over southern Texas during much of the period from July 17 to 24, transporting warm moist tropical air over that region. A cold, dry air mass to the north extended into Oklahoma and northern Texas. There was evidence of a front separating the two air masses at the surface on the 17th and 18th which remained more or less stationary. The rainfall was only moderately heavy during this time. However, following this time, when the heaviest rainfall occurred, there were no indications of a distinct front at the surface, the surface winds being southerly over most of Texas, and the excessive rains of the 21st to the 23d may be explained as follows: The strong southerly winds continued over southern Texas and extended to a considerable elevation following an anticyclonic curvature. In the cold air mass to the north the winds were northerly aloft, swinging to the northeast at high elevations. These opposing streams of contrasting air masses in the upper air caused convergence, or a piling up of the air, along a line situated approximately over the middle Colorado River Basin much of the time from about July 19 to 22. This lifting of the warm moist tropical air along the line of convergence produced general excessive rain over a limited area, mostly in the form of thunderstorms.

Heavy rainfall over much of eastern New Mexico during the first 10 days of September, although they did not cause any floods in the main streams, caused considerable overflow in the smaller streams.

TABLE 1.—*Precipitation (inches) in Colorado River Basin (Tex.), July 18 to 25, 1938, inclusive*

[Precipitation measured in morning unless otherwise indicated]

Station	July								Total
	18	19	20	21	22	23	24	25	
Austin [1]			0.06	0.13	0.39	0.62	0.06	T	1.26
Ballinger	0.10	T	T	T	.10	.70	T	.28	1.18
Big Spring	T	2.56	.09	1.31	.06	.15	.61	.49	5.27
Blanco					.15	.20	.40	.10	.85
Brackettsville					.37	3.69	5.92	.08	10.06
Brady	.04	.02	1.42	2.63	4.39	3.54	1.10	.51	13.65
Brownfield [2]				.16	.10				.26
Brownwood	1.23	.89	.21	.46	1.02	1.15	3.50	1.50	9.96
Coleman [2]	.23			.32	.21	.70	3.50	1.40	6.36
Columbus				1.26		.06		.23	1.55
Comanche [2]	T	.38		.44	.50	1.58	2.18	1.72	6.80
Eastland	T	1.10	.10	.07	T	2.35	1.30	1.20	6.12
Eden	.45	2.10	1.60	1.58	1.39	6.89	2.86	.02	16.89
Fort Stockton [2]	1.20	.80	.15	1.35	1.40	.15			5.05
Garden City [2]			.10		.25	.75	.90	.75	2.75
Gatesville [2]		2.35		.27	2.58	3.92	.14	.27	9.53
Goldthwaite [2]	T	1.50	.06	1.50	2.37	4.37	.83	1.76	12.39
Kerrville				.47	.13	.14	.72	.12	1.58
Knapp (near)[2]	.10	.12	.71		.45	.36	2.50	.34	4.58
Lamesa	.25	.20	.02	2.80	.05	.03	.05	.04	3.44
Lampasos			.92	.32	1.11	1,46	3.23	.96	8.00
Llano		T	.13	2.00	.51	.10	.70	6.75	10.19
Marble Falls					.01	1.70	.59	.14	2.44
McCamey			.03	.63	.40	.04	.22	.13	1.45
Menard			2.02	4.40	4.00	1.93	1.59	.19	14.13
Montell			.26	T	.70	1.42	2.04	.50	4.92
Morris Ranch [2] [3]		.04	.50	.90	.10	.07	.06	.85	2.52
Putnam [2]	1.55		1.02		2.18	.22	1.24	.12	6.33
Roscoe [2]	1.35	T	.54		.31	.18	.43	T	2.81
San Angelo	.28	T	1.32	.49	.13	.83	.36	.20	3.61
Seminole [2]	.63	T	.12	.39	.02	.37	T	1.62	3.15
Sloan [2]	.25	1.37	.70	3.70	3.92	8.47	.22	2.86	21.49
Smithville [2]				.61	.43	1.64	T	T	2.68
Snyder			.07	.92	.06	.21	1.47	.32	3.05
Sonora [2]			.12	.34	4.39	4.22	.44	3.04	12.55
Sterling City [2]	.20	.10		.30	.60	2.15	.10	1.75	5.20
Wharton					.09	.55	.37	1.43	2.44

[1] Midnight to midnight.
[2] 24 hours ending near sunset.
[3] Post office, Kerrville.

TABLE 2.—*Hourly gage readings, Colorado River at Austin, Tex., July 23–27, 1938*

Hour	July				
	23	24	25	26	27
A. M. 1		27.47	31.05	32.11	25.12
2		28.28	31.13	31.84	24.67
3		28.93	31.13	31.61	24.22
4		29.50	31.06	31.27	23.82
5		29.88	31.17	31.03	23.44
6		30.17	31.14	30.82	23.26
7		30.29	31.25	30.55	23.00
8		30.31	31.37	30.33	22.85
9		30.37	31.53	30.18	22.80
10		30.37	31.64	29.96	22.77
11		30.17	31.82	29.65	22.84
Noon		30.17	32.06	29.45	22.80
P. M. 1		30.15	32.15	29.20	22.72
2		30.09	32.60	29.05	22.60
3	15.76	30.04	32.76	28.84	22.36
4		30.07	32.90	28.41	22.12
5		30.14	33.01	28.24	21.85
6	18.76	30.19	[1] 33.05	28.00	21.56
7	20.26	30.31	33.00	27.80	21.05
8	21.51	30.47	33.03	27.43	20.75
9	22.82	30.58	32.84	27.13	
10	24.24	30.67	32.68	26.70	
11	25.62	30.87	32.48	26.13	
Midnight	26.73	30.98	32.28	25.67	

[1] Crest 33.05.

Flood losses during September 1938 [1]

Atlantic Slope drainage:	
Hudson River	[2] $5,220,000
Upper Susquehanna River	150,725
Neuse River	4,500
Missouri Basin:	
Small streams in Colorado	679,735
Fall River in South Dakota	25,000
Arkansas Basin: North Canadian River	49,350
West Gulf of Mexico drainage:	
Small streams in eastern New Mexico	116,500
Lower Rio Grande	8,175
Gulf of California drainage:	
Gila River	905
Verde River	550
Colorado River in Arizona	200
Total	6,255,640

[1] Estimates on damages in Connecticut and Merrimack and upper Mississippi Basins are not available.
[2] Includes damages also from wind and heavy rain.

Table of flood stages during September 1938

[All dates in September unless otherwise specified]

River and station	Flood stage	Above flood stages—dates From—	Above flood stages—dates To—	Crest Stage	Crest Date
ATLANTIC SLOPE DRAINAGE	*Feet*			*Feet*	
Pemmigewassett: Plymouth, N. H	11	20	23	23.6	21
Contoocook: Penocook, N. H	6	21	25	13.5	23
Nashua: East Pepperell, Mass	8			14.1	23
Merrimack:					
Franklin, N. H	14	20	24	28.5	22
Manchester, N. H	7	21	25	13.7	23
Lowell, Mass	55	21	24	63.0	23
Lawrence, Mass	25	21	24	31.4	23
White: West Hartford, Vt	18	22	22	19.4	22
Connecticut:					
South Newbury, N. H	22	21	24	27.9	22
White River Junction, Vt	18	21	24	26.6	22
Walpole, N. H	30	21	23	39.1	22
Montague City, Mass	28	21	25	44.6	22
Holyoke, Mass	9	21	25	14.9	22
Springfield, Mass	20	21	24	25.8	22–23
Hartford, Conn	16	21	28	35.4	23
Mohawk: Tribes Hill, N. Y	23	22	22	23.5	22
Hudson: Albany, N. Y	11	21	23	16.5	22
Lackawaxen: Hawley, Pa	6	21	22	(1)	21
Tioughnioga: Whitney Point, N. Y	12	21	24	13.3	22
Chenango:					
Sherburne, N. Y	8	22	22	8.4	22
Greene, N. Y	8	22	22	9.0	22

[1] Crest not obtained, gage read 8.8 at 8 a. m. of 22d.
[2] Flood stages continued into October.

Table of flood stages during September 1938—Continued

River and station	Flood stage	Above flood stages—dates From—	Above flood stages—dates To—	Crest Stage	Crest Date
ATLANTIC SLOPE DRAINAGE—continued	*Feet*			*Feet*	
Susquehanna:					
Oneonta, N. Y	12	21	25	21.3	22
Bainbridge, N. Y	12	21	24	16.7	22
Little: Kenly, N. C	8	19	22	15.4	21
Neuse:					
Goldsboro, N. C	14	22	25	18.0	24
Kinston, N. C	14	25	27	15.3	26
MISSISSIPPI SYSTEM					
Upper Mississippi Basin					
Chippewa: Durand, Wis	11	11	13	15.2	11
Black: Galesville, Wis	10	10	15	13.7	12
Wisconsin:					
Knowlton, Wis	12	Aug. 31	1	14.3	1
		9	12	19.9	11
Wisconsin Rapids, Wis	12	11	12	13.4	11–12
Wisconsin Dells, Wis	16	13	16	18.8	14
Portage, Wis	17	12	18	20.5	14
Rock: Moline Bridge, Ill	10	9	Oct. 5	11.9	18, 20, 22–26
Des Moines:					
Boone, Iowa	20	16	20	23.1	18
Tracy, Iowa	14	21	24	15.0	23–24
Ottumwa, Iowa	9	25	25	9.0	25
Mississippi:					
La Crosse, Wis	12	13	16	12.3	15
Prairie du Chien, Wis	18	17	20	18.4	18
Dubuque, Iowa	18	17	24	20.5	20
Clinton, Iowa	16	19	28	18.3	22, 23
Le Claire, Iowa	10	19	28	11.6	23
Davenport, Iowa	15	21	27	15.8	24
Muscatine, Iowa	15	19	Oct. 1	18.5	24
Keithsburg, Ill	12	20	30	14.3	25
Keokuk, Iowa	12	21	(2)	16.4	26
Quincy, Ill	14	21	(2)	18.3	27
Hannibal, Mo	13	20	(2)	18.1	27
Louisiana, Mo	12	21	(2)	16.3	28
Missouri Basin					
Big Sioux: Akron, Iowa	12	14	19	16.3	17
Arkansas Basin					
North Canadian:					
Woodward, Okla	5	6	7	5.3	7
Canton, Okla	6	7	9	9.1	8
Yukon, Okla	8	7	10	12.3	9
WEST GULF OF MEXICO DRAINAGE					
Rio Grande:					
Rio Grande City, Tex	21	Aug. 29	1	30.1	Aug. 31
Hidalgo, Tex	21	Aug. 30	3	24.7	2
Mercedes, Tex	21	Aug. 31	4	22.4	3
Brownsville, Tex	18	2	5	18.4	4
		29	Oct. 3	18.6	Oct. 1

WEATHER ON THE ATLANTIC AND PACIFIC OCEANS

[The Marine Division, I. R. TANNEHILL in charge]

NORTH ATLANTIC OCEAN, SEPTEMBER 1938

By H. C. HUNTER

Atmospheric pressure.—During most of the month the Azores HIGH was stronger than normal, but it was weak during the period from the 19th to 26th. It is worth noting that this was the time of special intensity of the Icelandic LOW; also the time when there occurred nearly all the particularly violent winds that were met over the eastern North Atlantic.

For the month as a whole, the southeastern North Atlantic had pressure averaging moderately above normal. Also in the region to the northeastward, including most of the vicinity of the British Isles, there was a slight excess; while to the northwestward and westward, the Grand Banks-St. Lawrence Gulf region likewise averaged a little above normal. Deficiencies appeared along the eastern coast of the United States and thence southward to the Bahamas and Puerto Rico, while the Greenland-Iceland area had a considerable deficiency.

The extreme pressure readings of the month found in vessel reports at hand are 30.68 and 27.85 inches. The former reading was reported by radio from an unidentified vessel near 46° north, 22° west, late on the forenoon of the 11th. The latter reading was radioed by the British steamship *Corrales*, in the month's hurricane, near 23° 23′ N., 67° 05′ W., about 7 p. m. of the 18th. Apart from data for the western Atlantic connected with the hurricane, the lowest reading found is 28.43 inches, near 51° N., 18° W., at a late hour of the 22d, noted by the American steamship *Collamer*.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, September, 1938*

Station	Average pressure	Departure	Highest	Date	Lowest	Data
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.64	−0.12	30.02	14	29.08	23
Reykjavik, Iceland	29.65	−.07	30.09	7	29.12	19
Lerwick, Shetland Islands	29.90	+.06	30.33	9	29.47	12
Valencia, Ireland	29.99	.00	30.39	9, 10, 11, 12	29.21	22
Lisbon, Portugal	30.07	+.05	30.21	18	29.92	25
Madeira	30.08	+.06	30.21	18, 19	29.89	21
Horta, Azores	30.24	+.07	30.46	29	29.86	22
Belle Isle, Newfoundland	29.95	+.06	30.38	18	29.42	24
Halifax, Nova Scotia	30.05	.00	30.32	18	29.70	24
Nantucket	30.02	−.06	30.34	10	29.39	21
Hatteras	30.00	−.06	30.26	26	29.26	21
Bermuda	30.08	.00	30.24	19	29.74	13
Turks Island	29.95	−.03	30.06	24	29.73	19
Key West	29.94	.00	30.12	24	29.79	20
New Orleans	30.00	+.02	30.19	24	29.81	14

NOTE.—All data based on a. m. observations only, with departures compiled from best available normals related to time of observation, except Hatteras, Key West, Nantucket, and New Orleans, which are 24-hour corrected means.

Extra-tropical cyclones and gales.—The North Atlantic experienced but one storm of importance that originated outside the Tropics. On the forenoon of the 20th there was a large area of comparatively low pressure covering most of the eastern North Atlantic to northward of 40° N., the area extending also far to the northwestward to cover most of the Greenland-Baffin Land region. Within the area, the most important low center at that time was near the south coast of Iceland. Rather strong winds covered a considerable area. Other centers developed of which the most important and the farthest to the south was well defined by the evening of the 21st, near 47° N., 23° W. From this position the center moved toward the north-northeast, and for a time gained in force. By the morning of the 23d it had passed well beyond the most-traveled steamship routes and was central about 300 miles west of northern Ireland. Thereafter it lost force, but was still in existence on the morning of the 24th close to southeastern Iceland.

The 22d was the day when vessels in transatlantic service encountered the gales in greatest numbers, chiefly between 43° and 51° N., and 12° and 27° W. As may be noted in the table of "Ocean gales and storms," two east-bound vessels met force 11 winds.

Tropical hurricane.—But one disturbance of tropical origin was noted over Atlantic waters during the month, but it was of great intensity and importance. A detailed description of this storm appears in this issue of the REVIEW. Here it may be remarked that the center appeared to the northeastward of the Leeward Islands late on the 16th, and at first advanced nearly westward till it was not far from the central Bahamas, then turned northward, passed not far from Hatteras on the 21st, and later crossed Long Island and the western part of New England. The track is shown on chart IX, which gives the synoptic situation on the 20th at Greenwich noon.

Vessel reports that have come by mail include 7 instances that appear in the table of "Ocean gales and storms," where winds of full hurricane force were experienced. Of these, 5 occurred in latitudes 25° to 30° N., and the others to northward of 38° N.

Fog.—On the whole, there was considerably less fog than had been noted during the preceding month. Such a decrease is expected during the fall season.

When the amount of fogginess is compared with the normal September situation, it appears there was a little more than usual over the northernmost areas from which numerous vessel reports come, also from areas near Newfoundland. On the other hand, there was less than normal fog in mid-ocean to southward of 50° latitude, and from near the southern limits of the Grand Banks westward to the vicinity of New England. The chief period of fog occurrence over the western North Atlantic was from the 12th to 23d, inclusive; but from the 8th to 13th was the main period for the eastern portion.

Two adjacent 5° squares reported the greatest number of days with fog, namely 10. These squares are located in 40° to 50° N., 45° to 50° W.

OCEAN GALES AND STORMS, SEPTEMBER 1938

Vessel	Voyage		Position at time of lowest barometer		Gale began September	Time of lowest barometer September—	Gale ended September	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				*Inches*					
Shenandoah, Am. S. S	Port Arthur	Charleston	24 50 N.	80 20 W.	7	Mdt, 7	8	29.96	S	S, 5	SE	SE, 8	S-SE.
American Shipper, Am. S. S.	Belfast	Boston	45 00 N.	56 41 W.	9	8a, 9	9	29.57	SSE	S, 6	NNW	WNW, 8	SE-S-WSW.
Black Gull, Am. S. S	New York	Rotterdam	46 00 N.	40 18 W.	14	2a, 14	14	29.70	W	W, 6	WSW	WSW, 8	WNW-WSW.
Colytto, Du. S. S	Grangemouth	Montreal	56 29 N.	41 07 W.	17	9a, 17	18	[1] 29.53	W	SSE, 6	NW	NNW, 9	
Socrates, Du. M. S	Cristobal	Liverpool	20 38 N.	59 17 W.	17	10p, 17	17	29.29	NNE	W, 11	WSW	W, 11	NW-WSW.
Robin Goodfellow, Am. S. S.	Trinidad	New York	21 15 N.	66 20 W.	18	4p, 18	19	29.66	NNW	NW, 8	SE	W, 8	NNW-SW.
Pan America, Am. S. S	do	do	28 27 N.	69 20 W.	18	10p, 18	19	29.69	N	NE, 8	E	NE, 8	N-NE.
Gulfhawk, Am. M. S	Philadelphia	Las Piedras	[2] 25 31 N.	69 54 W.	19	10a, 19	20	29.00	NE	E, 12	SE	E, 12	NE-SE.
Jean Lafitte, Am. S. S	Bremen	Tampa	[2] 27 47 N.	72 33 W.	19	4a, 20	20	29.31	ENE	ESE, 12	S	SSE, 12	E-SE.
Antigua, Am. S. S	New York	Santiago	27 06 N.	73 54 W.	19	4a, 20	20	28.24	NE	NE, 9	SSE	S, 9	NE-S-SE.
Atlantida, Hond. S. S	do	do	27 05 N.	74 35 W.	19	7a, 20	20	28.14	ENE	E, 12	SW	E, 12	NE-SE.
Phobos, Du. M. S	Falmouth	Baytown	[2] 27 39 N.	73 57 W.	19	10a, 20	20	28.81	E	S, 12	S	S, 12	SE-SSW.
Agwidale, Am. S. S	New York	Guantanamo	29 30 N.	72 35 W.	19	2p, 20	21	29.64	E	SSE, 9	S	S, 10	ESE-S.
India Arrow, Am. S. S	Chester	Harbor Is., Tex.	30 00 N.	75 40 W.	20	6p, 20	21	28.04	E	ENE, 12	NW	ENE, 12	E-NW.
Knoxville City, Am. S. S	New York	Cristobal	30 30 N.	72 30 W.	19	11p, 20	21	29.69	SE	S, 11	SW	S, 11	SE-SW.
San Benito, Pan. S. S	Baltimore	Santa Marta	36 14 N.	74 36 W.	21	10a, 21	21	28.60	E	N, 11	NW	N, 11	ENE-N-WNW.
Black Eagle, Am. S. S	Rotterdam	New York	50 00 N.	33 00 W.	21	10a, 21	22	29.38	NW	W, 6	NNW	NW, 9	WSW-NW.
Enterprise, U. S. N	On southern drill grounds.		36 52 N.	75 47 W.	21	10a, 21	21	29.39	N	NW, 9	W	NW, 10	N-W.
Gulfprince, Am. S. S	Portland, Me	Port Arthur	38 37 N.	73 54 W.	21	Noon, 21	21	28.82	NE	NNE, 9	NW	NW, 9	SE-N-NW.
Platano, Pan. S. S	Kingston	New York	38 20 N.	74 56 W.	21	Noon, 21	21	28.70		NW, 9		NW, 9	ENE-NW-W.
Birmingham City, Am. S. S.	New York	Newport News	[2] 38 55 N.	72 00 W.	21	1p, 21	21	28.10	ESE	SE, 12	WSW	SE, 12	ESE-SSW.
R. G. Stewart, Am. S. S	do	Baton Rouge	39 18 N	73 48 W.	21	1p, 21	21	28.64	NW	NW, 12	W	NW, 12	None.
Metapan, Am. S. S	Boston	Puerto Barrios	40 36 N.	69 26 W.	21	3p, 21	22	29.44	SSE	SE, 10	WSW	SE, 10	SE-SW.
Washington, Am. S. S	New York	Cobh	[2] 40 28 N.	73 50 W.	21	4p, 21	21	28.69	NE	WNW, 10	SW	W, 11	NE-NW-SW.
Duquesne, Am. S. S	Manchester	Galveston	46 24 N.	22 18 W.	21	11p, 21	22	29.15	WSW	WSW, 8	W	W, 8	

[1] Barometer uncorrected.
[2] Position approximate.

OCEAN GALES AND STORMS, 1938—Continued

Vessel	Voyage: From—	Voyage: To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began September	Time of lowest barometer September—	Gale ended September	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN—Continued													
Sarcoxie, Am. S. S.	Havre	Norfolk	50 50 N.	27 15 W.	21	3a, 22	23	29.03	S	WNW, 7	NW	NW, 9	W-NW.
Malvina, Du. M. S.	Rotterdam	Curacao	43 00 N.	20 30 W.	21	4a, 22	22	29.27	SW	SW, 8	WNW	SW, 10	SW-WNW.
Mopan, Br. S. S.	Liverpool	Kingston	[2]48 00 N.	16 50 W.	22	7a, 22	22	28.95	WSW	SW, 7	W	W, 9	S-WSW.
Dinteldijk, Du. M. S.	Halifax	London	[2]50 43 N.	17 09 W.	22	7a, 22	22	28.63	SSW	SSE, 7	SSW	SSW, 9	SSE-SSW.
West Hobomac, Am. S. S.	Corpus Christi	Bremen	48 40 N.	15 30 W.	22	8a, 22	23	29.00	SE	SE, 10	SW	SE, 10	SE-S.
Azalea City, Am. S. S.	Antwerp	Georgetown, S. C.	44 36 N.	19 30 W.	22	11a, 22	22	29.49	SW	W, 8	W	SW, 10	SW-W.
Sundance, Am. S. S.	Savannah	London	48 54 N.	22 30 W.	22	Noon, 22	23	28.61	W	W, 10	W	WNW, 11	W-WNW.
Waban, Am. S. S.	New Orleans	Havre	49 34 N.	13 20 W.	22	Noon, 22	23	28.98	S	S, 11	SSW	SSE, 11	SSE-SSW.
Chesapeake, Br. M. S.	Oxelosund, Sweden.	Baytown	[2]52 50 N.	21 16 W.	22	3p, 22	23	28.58	NNW	NNW, 9	NW	NW, 10	NE-NW.
Collamer, Am. S. S.	Havre	New York	50 53 N.	18 08 W.	22	7p, 22	23	28.43	SSE	SW, 6	W	W, 10	SSW-W.
Lubrafol, Belg. M. S.	Corpus Christi	Gothenburg	50 06 N.	18 36 W.	22	8p, 22	23	28.64	W	W, 10	WSW	W, 10	
American Merchant, Am. S. S.	New York	London	48 42 N.	21 00 W.	21	6a, 23	23	29.48	WSW	NW, 7	NW	NW, 9	None.
Mormacsun, Am. S. S.	Copenhagen	New York	57 50 N.	20 47 W.	22	8a, 23	23	28.75	ESE	N. 7	NW	NNW, 10	NE-NNW.
Frode, Dan. S. S.	Gothenburg	Portland,	[2]56 43 N.	28 32 W.	27	2a, 27	28	29.41	W	WSW, 6	WNW	W, 10	SSE-WSW.
American Trader, Am. S. S.	London	New York	45 52 N.	41 42 W.	28	1a, 29	29	29.73	SE	SSW, 8	W	W, 10	S-WNW.
NORTH PACIFIC OCEAN													
Shoyo Maru, Jap. S. S.	Estero Bay, Calif.	Yokohama	43 58 N.	168 34 W.	[3]31	Mdt. 31[3]	1	29.38	SSE	S, 9	W	S, 9	SSE-W.
Granville, Pan. M. S.	Los Angeles	Manila	21 13 N.	144 05 E.	1	8p, 1	2	29.57	ESE	NNE, 4	N	N, 9	ENE-N.
St. Mihiel, U. S. A. T.	San Francisco	Balboa	[2]15 33N.	97 55 W.	5	3a, 5	5	29.31	N	NE, 8	WSW	NE, 9	NE-SE-WSW.
Kahuku, Am. S. S.	Los Angeles	do	17 13 N.	101 42 W.	6	1p, 6	6	29.70	E	E, 8	E	E, 8	ESE-NE-S.
Tweedbank, Br. M. S.	San Francisco	Manila	36 11 N.	163 22 W.	5	5a 6	6	29.58	S	SW, 7	NW	SW, 10	S-W-SW.
Michigan, Am. S. S.	Los Angeles	Moskalevo	50 00 N.	155 00 E.	6	5a, 6	6	29.21	S	SW, 9	NW	NNW, 9	S-NW.
City of San Francisco, Am. S. S.	do	Acapulco	18 39 N.	104 39 W.	7	4p, 7	8	29.65	ESE	SE, 7	E	ESE, 10	SE-ESE.
Shikisan Maru, Jap. M. S.	Paramushiru	Los Angeles	47 53 N.	162 28 W.	7	1a, 7	9	[1]29.17	WSW	WSW, 3	SE	SSE, 8	
Saparoea, Du. M. S.	Cebu, P. I.	Portland, Oreg.	46 24 N.	162 36 W.	8	1p, 8	8	29.27	W	WNW, 6	W	W, 9	None.
Washington, Am. S. S.	Los Angeles	Balboa	19 27 N.	105 55 W.	8	6p, 8	9	29.68	E	SE, 7	SE	SE, 7	
Chirikof, Am. S. S.	Chignik, Alaska.	Larsen Bay, Alaska.	57 06 N.	155 30 W.	9	2a, 10	10	29.48		NNW, 8	NNW	NNW, 8	NW-NNW.
Kailua, Am. S. S.	Port Allen, H. I.	San Francisco	37 00 N.	125 30 W.	10	4p, 11	11	29.87	NNE	NNW, 3	NNE	NNE, 8	
Washington, Am. S. S.	Los Angeles	Balboa	15 25 N.	97 25 W.	11	9a, 11	11	29.42	NNE	NE, 9	SW	S, 10	NNE-S.
Virginian, Am. S. S.	do	do	16 50 N.	99 04 W.	11	7p, 11	11	29.65	W	SW, 9	SSW	SW, 9	W-SW.
Daini Ogura Maru, Jap. M. S.	Yokohama	San Francisco	39 43 N.	151 12 W.	13	7p, 13	14	29.20	WNW	WNW, 7	NW	WNW, 8	WSW-NW.
Geflon, Nor. M. S.	do	Port San Luis	42 12 N.	148 54 W.	18	2p, 18	19	29.93	W	W, 8	W	W, 9	WSW-W.
Empress of Canada, Br. S. S.	Victoria, B. C.	Honolulu	42 26 N.	135 38 W.	18	2a, 19	19	29.46	S	S, 8	W	WSW, 8	S-WSW.
Nankai Maru, Jap. M. S.	Yokohama	San Francisco	43 53 N.	139 05 W.	18	6a, 19	19	28.94	SW	S, 8	WSW	S, 8	S-SW.
Hikawa Maru, Jap. M. S.	do	Vancouver, B. C.	49 05 N.	129 05 W.	19	6a, 19	19	29.46	SE	SE, 8	ESE	ESE, 8	SE-ESE.
Shoyo Maru, Jap. S. S.	do	Los Angeles	41 00 N.	160 00 W.	19	10a, 19	19	29.10	SE	SE, 11	S	SE, 11	SE-S.
Frank G. Drum, Am. S. S.	Los Angeles	San Jose, Guatemala.	[2]15 17 N.	96 32 W.	23	10p, 22	23	[1]29.86	N	NE, 3	N	N, 7	
San Clemente Maru, Jap. M. S.	Yokohama	San Francisco	40 12 N.	151 50 E.	23	Mdt. 21	24	29.54	WNW	WNW, 5	NW	WNW, 9	SSE-WNW-W.
Golden Cloud, Am. S. S.	Balboa	Honolulu	17 52 N.	120 30 W.	24	1a, 25	25	[1]29.66	NNE	W, 9	SW	W, 9	NW-WSW.
Pearleaf, Br. Navy	Singapore	Hong Kong	16 19 N.	113 18 E.	24	1a, 25	26	29.61	ENE	ENE, 8	ENE	ENE, 8	
China Arrow, Am. S. S.	Vladivostok	Los Angeles	45 07 N.	152 34 E.	25	8p, 25	27	29.24	ESE	SSE, 6	N	W, 8	SE-SW.
Do	do	do	49 40 N.	177 54 E.	30	8a, 30	[4]1	29.43	ENE	N, 10	NW	NE, 10	NE-NNW.

[1] Barometer uncorrected. [2] Position approximate. [3] August. [4] October.

NORTH PACIFIC OCEAN, SEPTEMBER 1938

By WILLIS E. HURD

Atmospheric pressure.—Pressure contrasts were abnormally developed for the month in the regions of the Aleutian LOW and the North Pacific HIGH in September 1938. The LOW was central over the western waters of the Gulf of Alaska, with pressure at Kodiak, 29.59 inches (or 0.12 inch below the normal), the lowest of record for the month in the past 13 years. The HIGH was central in midocean, with barometer at Midway Island, 30.12 inches (or 0.11 inch above the normal), the highest of record for the month since 1917. At Kodiak the average September fall in pressure from the mean barometer of August was 0.51 inch. The Aleutian LOW, therefore, is seen to have developed, especially for this early in the season, with unusual rapidity.

Except over the two "centers of action," the changes from normal pressure were small.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean, September 1938, at selected stations*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow	29.69	−0.21	30.04	3, 4, 5	29.20	16
Dutch Harbor	29.64	−.12	30.30	30	29.14	23, 24
St. Paul	29.71	.00	30.20	30	29.18	23, 24
Kodiak	29.59	−.12	30.16	1	29.14	12
Juneau	29.89	−.03	30.14	13	29.40	20
Tatoosh Island	30.04	+.04	30.32	25	29.79	17
San Francisco	29.94	.00	30.16	25	29.76	7
Mazatlan	29.84	+.02	29.98	24	29.70	7, 12
Honolulu	29.97	−.03	30.07	24	29.88	13
Midway Island	30.12	+.11	30.24	25	29.94	4, 5
Guam	29.78	−.05	29.86	26, 27	29.68	18, 19
Manila	29.74	−.03	29.83	13–16	29.56	30
Hong Kong	29.76	−.01	29.86	22	26.62	4
Naha	29.81	+.05	29.97	13	29.56	4
Titijima	29.82	−.04	30.00	26, 27	29.62	22

NOTE.—Data based on 1 daily observation only, except those for Juneau, Tatoosh Island, San Francisco, and Honolulu, which are based on 2 observations. Departures are computed from best available normals related to time of observation.

Extratropical cyclones and gales.—A few cyclones entered the northwestern part of the ocean from Asia, but the greater part of the extratropical cyclonic developments of the month occurred over northeastern waters concentrating between the vicinity of the Alaskan Peninsula and about the fortieth parallel to the southward.

To the westward of the one hundred eightieth meridian only one gale was reported prior to the 23d; that occurred on the 6th, southeast of Kamchatka. On the 23d and 26th, wind forces of 8 to 9 were experienced along those parts of the northern routes lying south of the Kuril Islands, and on the 30th a whole gale (force 10) was encountered south of the Aleutians.

In west longitudes there was a wider and more frequent distribution of storminess, with gales reported on 7 or 8 days within the area 35° to 55° N., 170° W. and the American coast. Scattered fresh-to-strong gales occurred on the 1st, 8th, 11th, 13th, and 14th, and a whole gale on the 6th; but it was not until the 19th that storminess overspread a considerable region, extending from the Washington coast and Vancouver Island west-southwestward two-thirds of the way toward Midway Island. Over the eastern half of the area the gales reported on the 19th did not exceed force 8. The most intense wind of the day was a brief gale of force 11, encountered by the Japanese steamer *Shoyo Maru*, in 41° N., 160° W. The ship's lowest barometer was 29.10. The lowest pressure occurring in an extratropical cyclone of the month was 28.56, reported by radio on the 19th by the British steamer *Eurypylus* from near 50° N., 140° W.

Following the 19th there was very little storminess in northeastern waters.

Tropical cyclones off the west coast of Mexico.—A shallow depression appeared south of Cape Corrientes on September 1 and passed inland from the Gulf of California on the 3d. No gales were reported in connection with it.

The only cyclone of the month in this locality, the track of which can be drawn with some approximation, was that of the 4th to 13th. Wind and pressure conditions on the lower part of the Gulf of Tehuantepec late on the 4th were indicative of the formation of a Low. On the early morning of the 5th the U. S. A. T. *St. Mihiel*, southbound in the vicinity of 15½° N., 98° W., ran into a succession of winds shifting over a period of about 2 hours from north, through northeast and southeast to southwest. The cyclone was of some intensity, with a maximum wind force of 9, accompanied by momentary stronger squalls, from northeast, lowest barometer 29.31. On the 6th cyclonic circulation was indicated specifically by a report from the American steamer *Kahuku*, but her lowest barometer was only 29.70, with strongest wind east, force 8, in 17°13′ N., 101°42′ W., at about local noon.

The disturbance continued to move slowly northwestward, the center lying at about 100 miles from the coast between Acapulco and Manzanillo. The southbound steamer *City of San Francisco* was considerably under the influence of the cyclone from 8 a. m. of the 7th until 6 a. m. of the 8th, with strong southeasterly winds throughout, rising to force 10 during the afternoon of the 7th, lowest barometer 29.65. The highest winds reported thereafter in connection with the disturbance, as it moved slowly past Cape Corrientes and across the mouth of the Gulf of California, were of force 7. The cylcone persisted weakly until the 13th, when it disappeared at sea off the southern west coast of Lower California.

While the disturbance already described was in progress, another cyclone formed and dissipated suddenly on the 11th close off the coast between Salina Cruz and Acapulco. Its entire known history, at this writing, is embraced in the storm reports of the American steamers *Washington* and *Virginian*, both from Los Angeles toward Balboa. The *Washington* met gales shifting from northeast, force 9, at 9 a. m. (local time), to south, force 10, at 10 a. m., lowest barometer 29.42, in 15°25′ N., 97°25′ W. The *Virginian* had a maximum wind of force 9 from the southwest at 7 p. m. of the 11th, in 16°50′ N., 99°04′ W., lowest barometer 29.65.

On the afternoon of the 24th and continuing into the 25th, the American steamer *Golden Cross*, westbound, entered into a stormy region near 18° N., 120° W. The gale began from the north-northeast, force 8, and ended from a westerly direction, highest force 9, lowest pressure, uncorrected, 29.66. A cyclone was evidently in progress to the westward of the Revillagigedo Islands.

A moderate north gale occurred in the Gulf of Tehuantepec on the morning of the 23d. Apparently it was a Tehauntepecer—the first of the season.

Typhoons and depressions of the Far East.—There were several disturbances in tropical waters of the Far East during September. A complete discussion of them by the Rev. Bernard F. Doucette, S. J., of the Manila Observatory, is anticipated and will be published in a later REVIEW if not received in time for the current issue.

From our own meager reports it appears that a cyclone of some energy lay over the Marianas on September 1. The Panaman motorship *Granville* on that date had a north gale of force 9, lowest barometer 29.57, near 21° N., 144° E. On the 4th a depression is shown on our maps east of the Nansei Islands. On the 5th it had moved to southern Japan, where it is indicated to have been of considerable depth and accompanied by strong gales. This was over the same region that had been hard hit by the disastrous typhoon of the night of August 31–September 1, mentioned in the preceding issue of the Review.

Late in the month another typhoon raged in the China Sea. Very early on the 25th the British Navy vessel *Pearleaf* reported an east-northeast gale of force 8, barometer 29.61, in 16°19′ N., 113°18′ E. On the 26th to 28th a strong typhoon moved west toward the coast of Indo China, and thence northward into the Gulf of Tonking, where it appears to have been of great energy.

Fog.—Early autumn brought a lessening in fog production on the North Pacific, especially in higher middle latitudes, east of the one hundred and eightieth meridian, where it was unusually frequent in August and unusually scarce in September. The principal fog belt of the month lay along the western third of the northern steamer routes, with some 10 to 15 percent of days with fog. In United States coastal waters fog was reported off Washington on 4 days; off California on 6 days; and off Lower California on 2 days.

LATE REPORT: TYPHOONS AND DEPRESSIONS OVER THE FAR EAST, AUGUST 1938

By BERNARD F. DOUCETTE, S. J.

[Weather Bureau, Manila, P. I.]

Typhoon, August 4–13, 1938.—From August 4 to 8, a disturbance apparently of mild intensity moved in a west-northwesterly direction from the ocean regions about 300 miles south-southeast of the Bonins to the northern Nansei (Loochoo) Islands. Because of insufficient observations it was not certain that the storm had intensified to typhoon strength until it was in the Eastern Sea, about 250 miles east of Shanghai (August 9, 6 a. m.). It continued moving west-northwest into the continent, passing over the coast line about 80 miles north of Shanghai during the early morning hours of August 10. During the

same day, it changed its course to the north-northwest, and the following day found it moving more slowly as it recurved to the northeast, passing close to and north of the Shantung Peninsula. It then weakened into a mild LOW center, moving eastward, August 13, after which no trace of it could be found.

The U. S. S. *Oahu* reported, August 10, 8:30 a. m., from "mileage 150" (vicinity of Nanking), "typhoon weather wind steady north-northwest, force 8, barometer down zero point one seven last hour to 29.23 at 0800; rain, visibility zero point one; appear to be in path of center."

During the period of formation and early history of this storm, the upper winds over Guam were from the southwest quadrant, and increased from values less than 20 k. p. h. to values between 40 and 60 k. p. h., and then decreasing as the storm moved toward the Nansei Island. Over the Philippines, the predominating directions were those of the southwest quadrant, Zamboanga however having east and southeast quadrant winds, hardly ever over 30 k. p. h. An increase of velocity appeared at Aparri, August 11, simultaneous with the formation of the typhoon of August 10 to 19. During the whole course of the typhoon, there was a high easterly current over Manila, always evident by the movement of the high clouds, but not appearing in the ascension reports of the pilot balloon observations.

Typhoon, August 10–19, 1938.—The afternoon weather map of August 10 gave evidence of the presence of a well-developed typhoon central near latitude 21° N., longitude 134° E., about 700 miles in an easterly direction from Basco, Batanes Islands. The typhoon moved in a west-northwesterly direction, inclining to the northwest as the center passed about 60 miles northeast of Ishigakijima (August 13, 6 a. m.). Two days later the center was about 200 miles north-northwest of this station, from which position it recurved to the north-northeast, moving rapidly toward Chosen (Korea) and passing over that region into the Sea of Japan, where it lost strength as it inclined to the east, north of the Sea of Japan.

Upper wind data, obtained from stations in the Philippines, showed the presence of a current of air from the southwest quadrant flowing over the whole archipelago, except southern Mindanao (Zamboanga) where east and southeast quadrant winds predominated. Simultaneous with the period of formation of this typhoon, the velocities at Aparri increased to values between 30 and 60 k. p. h. and maintained these values, August 9 to 14, then decreased, the strongest winds occurring August 9 and 10. On the western side of the China Sea, Siam, and Indochina, pilots showed that a steady southwest quadrant current existed, with values from 20 to 75 k. p. h., during this whole typhoon period and not weakening until August 16.

Typhoon August 19–23, 1938.—As before, a storm of considerable strength quickly formed over the ocean regions east of the Philippines, this time about 500 miles east of northern Luzon (August 19, 2 p. m.). The center moved northwest overnight and then inclined to the west-northwest the next day, a course which directed it across southern Formosa into the southern part of the Formosa Channel, where it disappeared.

After the preceeding typhoon had filled up, an easterly current prevailed over the Philippines, which was replaced, on August 18, by west and southwest quadrant winds, Zamboanga alone reporting east and southeast quadrant winds aloft. Velocities at Aparri, Manila, and Cebu remained less than 40 k. p. h. during the course of the typhoon.

Typhoon August 22–28, 1938.—A low pressure area, east of central Luzon, intensified and manifested itself as an active center near latitude 16° N., longitude 130° E., about 550 miles east-northeast of Manila (August 22, 6 a. m.). For about a day and a half the storm moved west-northwest and then suddenly recurved to the northeast, when about 250 miles east of northern Luzon. It then moved to the regions about 650 miles east of southern Formosa, inclined to the north and moved rapidly to Kiusiu Island. This island was afflicted with the typhoon center during the night of August 26–27, after which the storm existed for 1 day in the Sea of Japan, no trace of it appearing on the afternoon maps of August 28. There was severe flood damage to a large part of Japan due to this typhoon, but full details were not published in Manila papers.

In connection with the formation of this typhoon, only the upper winds over Cebu showed any increase in velocity of the steady southwest quadrant current flowing over the Archipelago, about 25 k. p. h. or less. After August 18 velocities over Cebu gradually increased to values as high as 40 k. p. h. August 21 and 22. Up to the afternoon of August 22, Zamboanga had east and southeast quadrant winds and then changed to the southwest quadrant, reporting these directions until August 24, when the east quadrant winds returned. Velocities during these days seldom reached values over 30 k. p. h. at any level at this station.

Typhoon August 24–28, 1938.—The map for August 24, 6 a. m. indicated by the fall in pressure at Laoag and Vigan that a disturbance was developing over the China Sea west of northern Luzon. It did not take long to intensify as it moved along a west-by-north course across the China Sea, passing over Hainan Island, where it inclined to the west-northwest, thus moving across the Gulf of Tong King into Indochina, passing close to and north of Phulien (August 28, morning). It rapidly disappeared after entering the continent.

The observations reported by the S. S. *Jeypore* seem to be significant concerning the formation of this typhoon. At 0000 G. M. T. August 23, this vessel was in latitude 18°17′ N., longitude 119°59′ E., and reported "barometer 29.63 corrected, rising slowly, temperature 80°, southeast 5, heavy swell, moderate southerly sea, overcast, frequent heavy rain squalls." This was at the time when the typhoon described above (August 19–23) was entering the Formosa Channel, where it disappeared. It is possible that this typhoon formed as a secondary disturbance depending upon the previous storm. The weather reported by the S. S. *Jeypore* is the only basis of this supposition.

This typhoon formed at the time that sudden changes in velocities occurred over Siam stations. Up to August 20, with the directions from the southwest quadrant, the velocities reported were between 5 and 60 k. p. h. No reports were received August 21, but on August 22, velocities were in general between 40 and 80 k. p. h. These values did not decrease until after August 24. This increase in velocity did not manifest itself anywhere in the Philippines, where reported velocities never reached values over 45 k. p. h., not increasing nor decreasing to any great extent during the period. It has happened that an increase in velocity at stations along the west of the China Sea would manifest itself over the Philippines about a day or so later. In the case of the typhoon under discussion, this increase, or "surge," did not travel across the China Sea. It is an example, not sufficient for forming a rule, to illustrate the use of pilot balloon data for forecasting purposes, for in this case the uniformity of velocities reported from Philippine stations in connection with the increase of velocities over regions west of the China Sea could be taken as an indication of the development of a disturbance in the China Sea.

CLIMATOLOGICAL TABLES[1]

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

TABLE 1.—*Condensed climatological summary of temperature and precipitation by sections, September 1938*

Section	Temperature								Precipitation					
			Monthly extremes								Greatest monthly		Least monthly	
	Section average	Departure from the normal	Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	75.3	−0.4	Greensboro	102	9	St. Bernard	39	22	1.40	−2.12	Evergreen	5.06	2 stations	0.10
Arizona	74.6	+1.8	2 stations	112	[2] 9	Alpine	28	22	.87	−.38	Tombstone	4.84	3 stations	.00
Arkansas	75.7	+1.3	Conway	107	1	Thornburg	32	20	1.55	−1.82	St. Charles	4.32	Calico Rock	.11
California	69.6	+2.0	Cow Creek	114	[2] 2	Boca	20	6	.37	−.07	Cummings	1.98	31 stations	.00
Colorado	60.3	+2.3	2 stations	99	[2] 26	Fraser	17	28	3.01	+1.66	Waterdale	10.22	Trinidad	.43
Florida	78.7	−.7	Ocala	100	[2] 5	Mason	40	23	5.84	−.85	Apalachicola	14.45	Pensacola	.54
Georgia	74.8	−.6	2 stations	100	[2] 1	Blairsville	32	22	2.70	−.97	Savannah No. 2	8.46	Canton	.01
Idaho	63.2	+6.2	Orofino	107	3	Obsidian (near)	20	6	.54	−.49	Mullan	1.91	9 stations	T
Illinois	69.0	+1.2	2 stations	102	[2] 8	3 stations	35	19	3.11	−.66	Dixon	8.79	Grand Chain	.53
Indiana	68.2	+1.0	Johnson	104	7	Collegeville	32	19	2.94	−.47	Brookville	9.85	Seymour	.81
Iowa	66.8	+3.0	Ottumwa	101	7	Inwood	29	19	5.67	+1.82	Britt	13.64	Albia	.68
Kansas	72.3	+2.6	2 stations	103	10	7 stations	31	[2] 19	2.19	−.63	Paola	6.29	Cawker City	.29
Kentucky	70.3	−.2	Henderson	101	8	Mammoth Cave	37	20	3.52	+.53	Smith's Grove	8.98	Carrollton	1.00
Louisiana	77.2	−.8	Plain Dealing	104	1	Tallulah	41	[2] 21	2.85	−1.02	Crowley	7.80	Bastrop	.39
Maryland-Delaware	65.8	−1.9	3 stations	92	[2] 4	Grantsville, Md.	32	26	6.11	+2.94	Princess Anne, Md.	9.72	Mount Savage Summit, Md.	1.59
Michigan	58.5	−1.9	Monroe	92	12	Sidnaw	27	29	2.73	−.60	Sack Bay	5.37	Sidnaw	.79
Minnesota	60.6	+1.5	Waseca	97	4	Hallock	24	19	3.62	+.75	Worthington	11.16	Big Falls	.10
Mississippi	76.1	+.2	2 stations	102	[2] 6	Batesville	38	20	1.41	−1.62	Hickory	5.17	Fulton	.08
Missouri	71.6	+2.3	4 stations	103	[2] 7	Dean	30	20	1.85	−2.25	Willow Springs (near)	5.89	Philadelphia	.19
Montana	62.5	+7.5	Libby	100	[2] 1	Wisdom	22	[2] 26	.87	−.47	Glasgow	4.72	3 stations	.00
Nebraska	67.4	+3.2	Fairbury	103	10	2 stations	27	19	2.88	+.82	Virginia	9.32	Benkelman	.88
Nevada	66.0	+4.8	Las Vegas	107	3	San Jacinto	28	9	.16	−.24	Searchlight	.75	2 stations	.00
New England	57.9	−2.3	Nashua, N. H.	88	21	First Connecticut, Lake, N. H.	25	9	9.27	+5.42	Hubbardston, Mass.	18.28	Presque Isle, Maine	2.8
New Jersey	63.6	−2.3	Canoe Brook	95	4	Charlottebury	30	10	9.67	+6.11	Long Branch	11.81	Newark	6.29
New Mexico	63.7	−.7	Carlsbad	97	30	Elizabethtown	21	30	3.30	+1.61	Lee Ranch	9.26	Gower	.11
New York	57.6	−3.6	Brockport	90	1	Indian Lake	24	30	7.59	+4.10	Setauket	13.15	Auburn	3.56
North Carolina	70.8	−.2	2 stations	98	[2] 14	Mount Mitchell	26	22	5.90	+1.87	Swansboro	22.50	Greensboro	1.05
North Dakota	61.9	+5.1	do	99	22	2 stations	21	19	.63	−.90	Hankinson	4.24	Hansboro	.00
Ohio	65.7	+.1	Gallipolis	98	[2] 5	do	34	[2] 20	4.02	+1.02	Jefferson	9.29	Larue	1.29
Oklahoma	75.6	+1.4	2 stations	105	[2] 1	do	32	20	1.84	−1.31	Waukomis	8.13	Wyandotte	.16
Oregon	61.9	+4.2	do	103	[2] 14	Chemult	24	13	.85	−.34	Rujada	4.09	Canyon City	.02
Pennsylvania	62.0	−2.2	Marcus Hook	95	4	Coudersport	26	26	4.74	+1.34	Mount Pocono	10.46	Kylertown	1.39
South Carolina	74.5	.0	3 stations	99	[2] 3	Longcreek (near)	39	22	4.92	+.78	Lake City	13.63	Walhalla	.77
South Dakota	65.4	+3.9	Armour	104	23	LaDelle (near)	22	19	2.34	+.82	Canistota	7.76	Hardy Ranger Station	.38
Tennessee	71.1	−.4	Union City	101	9	Rugby	35	21	2.73	−.33	Celina	6.15	Chattanooga	.32
Texas	77.7	+.4	Henrietta	106	[2] 1	Bridgeport	39	21	1.57	−1.32	Galveston	7.13	2 stations	.00
Utah	64.2	+3.5	St. George	99	[2] 3	Woodruff	24	26	.76	−.23	Monticello	2.90	4 stations	.00
Virginia	67.5	−1.1	3 stations	95	[2] 4	Big Meadows	35	22	3.99	+.84	Onley	9.82	Roanoke	1.23
Washington	64.0	+5.9	4 stations	104	[2] 2	Deer Park	29	[2] 5	.92	−.94	Clearwater	6.14	Sunnyside	T
West Virginia	65.8	−.6	3 stations	95	[2] 4	Bayard	28	26	3.59	+.67	Spruce Knob	7.30	New Martinsville	1.63
Wisconsin	59.6	−.7	Wisconsin Dells	94	4	Long Lake	28	21	7.27	+3.56	Brodhead	13.50	Plum Island	2.39
Wyoming	59.0	+4.3	Thermopolis	95	[2] 19	Gallatin	18	17	1.27	+.14	Archer	5.43	Basin	.00
Alaska (August)	53.2	+.5	2 stations	82	[2] 7	Stuyahok	26	24	4.25	+.90	Scotch Cap	10.54	Whale Island	.29
Hawaii	75.5	+.8	Mahukona	93	7	Kanalohuluhulu	41	13	2.95	−3.05	Keauhou No. 2	17.93	12 stations	.00
Porto Rico	78.4	−.2	3 stations	96	[2] 15	Guineo Reservoir	59	[2] 11	8.35	−.28	La Fe	19.51	Culebra Island	2.56

[1] For description of tables and charts, see Review, January, p. 29.
[2] Other dates also.

TABLE 2.—*Climatological data for Weather Bureau stations, September 1938*

[Compiled by Annie E. Small, by official authority U. S. Weather Bureau]

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							59.6	−1.2										80	8.47	+5.4										5.3		
Eastport	75	67	85	29.94	30.02	−0.01	56.0	+0.2	72	21	63	43	26	49	23	52	50	85	5.44	+2.7	15	10.5	sw.	32	se.	21	10	7	13	6.0	0.0	0.0
Greenville, Me.	1,069	4	41	28.96	30.02		52.7		74	11	64	27	29	42	38	49	47		5.32		15		nw.				7	6	17		.0	.0
Portland, Me.	103	82	117	29.89	30.02	−.03	58.7	−.9	80	1	66	44	30	51	29	53	49	76	6.47	+3.4	11	9.3	n.	43	s.	21	14	6	10	4.4	.0	.0
Concord	289	54	72	29.71	30.02	−.04	58.4	−.9	79	4	69	37	10	48	37				10.68	+7.2	14	5.6	n.	56	se.	21	13	6	11	4.8	.0	.0
Burlington	403	11	48	29.55	29.99	−.07	55.3	−5.0	78	4	64	34	30	46	31	52	49	81	6.87	+3.4	13	9.1	s.	47	s.	21	9	4	17	5.9	.0	.0
Northfield	876	12	60	29.07	30.02	−.04	53.0	−3.1	76	4	64	28	30	42	39	49	47	86	7.56	+4.5	14	7.3	s.	47	s.	21	8	5	17	6.6	.0	.0
Boston [1]	29	33	62	29.98	30.01	−.06	62.2	−1.0	82	1	70	45	9	54	27	56	52	77	6.00	+2.9	12	12.0	nw.	73	s.	21	10	7	12	5.4	.0	.0
Nantucket	12	14	90	30.01	30.02	−.06	63.0	+.2	76	19	68	52	25	58	17	59	57	82	9.55	+7.1	14	14.9	s.	52	se.	21	16	7	7	4.2	.0	.0
Block Island	26	11	46	29.99	30.02	−.06	62.5	−.9	74	1	68	50	9	57	20	59	56	82	6.31	+3.6	14	15.0	sw.	82	se.	21	13	6	11	4.5	.0	.0
Providence	159	215	251	29.85	30.02	−.05	62.6	−.6	85	1	72	44	9	54	28	57	53	76	5.16	+2.0	11	11.6	nw.	87	sw.	21	13	4	13	5.3	.0	.0
Hartford	159	66	100	29.85	30.02	−.05	61.7	.0	83	4	71	40	10	52	29				14.59	+11.1	13	7.7	n.	46	ne	21	13	4	13	5.4	.0	.0
New Haven	106	74	153	29.91	30.02	−.05	62.3	−1.2	83	4	71	43	10	54	26	57	53	77	14.52	+11.0	14	9.5	n.	38	ne.	21	10	6	14	5.6	.0	.0
Middle Atlantic States							65.7	−1.3										78	6.52	+3.3										6.5		
Albany [1]	292	26	37	29.68	30.00	−.07	58.6	−4.5	83	4	69	34	26	48	39	53	50	82	8.76	+5.6	14	8.7	s.	42	w.	21	9	9	12	6.0	.0	.0
Binghamton	871	57	79	29.10	30.04	−.03	58.9	−2.4	84	4	69	36	26	49	39	53	50	82	5.74	+2.6	13	6.0	ne.	20	nw.	21	3	8	19	7.7	.0	.0
New York	314	415	454	29.68	30.01	−.07	64.9	−1.9	82	4	72	49	25	58	23	58	53	73	8.77	+5.4	11	13.5	n.	70	nw.	21	9	7	14	5.9	.0	.0
Harrisburg	374	94	104	29.62	30.02	−.06	64.1	−1.7	90	4	72	44	26	56	28	57	53	72	4.41	+1.4	14	6.8	ne.	22	nw.	21	9	9	12	5.9	.0	.0
Philadelphia	114	174	367	29.91	30.02	−.06	66.3	−1.7	85	4	74	51	22	59	24	59	55	74	7.35	+4.2	15	12.1	n.	37	nw.	21	8	8	14	6.1	.0	.0
Reading	323	283	306	29.68	30.03		64.1	−2.2	86	4	72	43	26	56	31	58	54	74	4.70	+1.5	13	9.7	n.	31	nw.	21	8	9	13	5.7	.0	.0
Scranton	805	72	104	29.16	30.02	−.05	60.6	−2.3	84	4	70	36	26	51	37	54	50	74	5.42	+2.2	14	6.4	n.	24	nw.	24	7	12	11	6.3	.0	.0
Atlantic City	52	37	172	29.96	30.01	−.06	67.0	+.2	84	24	72	51	26	62	23	62	59	79	11.76	+9.1	14	15.0	n.	61	w.	21	7	11	12	6.2	.0	.0
Sandy Hook	22	10	57	29.99	30.01		65.8	−1.7	83	4	71	53	30	60	19	60	56	76	11.15	+7.7	14	13.7	sw.	56	n.	21	9	7	14	5.9	.0	.0
Trenton	190	89	107	29.82	30.02		64.4	−2.5	86	4	73	46	26	56	28	58	55	77	9.04	+5.6	11	8.2	n.	37	nw.	21	8	8	14	6.3	.0	.0
Baltimore	123	100	215	29.89	30.02	−.06	68.0	−.5	90	15	75	48	22	61	27	61	57	74	5.05	+1.7	14	9.5	sw.	35	nw.	21	8	6	16	6.6	.0	.0
Washington	112	62	85	29.90	30.02	−.06	67.4	−.7	90	4	75	48	26	60	31	61	58	78	4.27	+1.0	13	5.8	sw.	27	nw.	21	6	9	15	6.6	.0	.0
Cape Henry	18	8	54	29.99	30.01		71.6	−.2	90	15	78	49	22	65	24	67	65	84	8.38	+5.5	14	11.5	sw.	54	nw.	21	6	8	16	6.9	.0	.0
Lynchburg	686	144	184	29.31	30.05	−.03	68.9	−.1	92	5	77	48	22	60	29	62	59	79	1.87	−1.4	13	6.2	w.	30	nw.	21	3	9	18	7.5	.0	.0
Norfolk	91	80	125	29.92	30.02	−.04	71.8	+.2	93	15	79	50	22	65	26	65	63	81	7.76	+4.5	15	8.7	sw.	34	nw.	21	6	5	19	7.5	.0	.0
Richmond	144	11	52	29.88	30.03	−.04	69.0	−1.5	90	5	78	46	22	60	31	63	61	83	3.85	+.6	10	6.9	ne.	28	n.	21	8	9	13	6.2	.0	.0
Wytheville	2,304	49	55		30.06	−.01	65.0	+1.4	85	5	74	46	22	56	29				2.59	−.7	15	5.4	w.	19	nw.	21	4	8	18		.0	.0
South Atlantic States							74.6	+1.3										79	5.64	+1.4										5.9		
Asheville	2,253	89	104	27.74	30.05	−.02	67.4	+2.4	88	8	78	42	22	57	35	60	58	83	4.72	+1.7	12	6.1	nw.	21	nw.	21	6	16	8	6.1	.0	.0
Charlotte	779	63	86	29.20	30.02	−.05	73.0	+1.5	93	5	82	49	21	64	30	64	61	74	3.44	+.4	5	6.0	sw.	21	ne.	29	5	13	12	6.7	.0	.0
Greensboro [1]	886	6	56	29.11	30.06		70.0		92	5	80	41	22	60	35	63	61	82	.89		5	7.1	ne.	24	ne.	29	5	7	18	7.1	.0	.0
Hatteras	11	5	50	29.99	30.00	−.06	75.5	+1.0	87	5	81	61	22	70	15	71	69	83	10.17	+5.6	12	11.9	sw.	61	nw.	21	9	15	6	5.1	.0	.0
Raleigh	376	103	140	29.62	30.01	−.06	71.6	+.5	93	5	80	51	22	63	26	65	62	80	4.85	+1.2	10	7.6	ne.	27	nw.	21	10	11	9	5.3	.0	.0
Wilmington	72	73	107	29.94	30.01	−.04	74.9	+1.8	92	15	83	55	23	67	24	69	67	83	16.28	+11.8	15	7.8	sw.	26	nw.	21	8	11	11	5.8	.0	.0
Charleston	48	11	92	29.96	30.01	−.03	77.6	+1.0	94	14	85	58	21	71	22	71	68	79	5.24	+.7	11	8.5	s.	43	sw.	29	7	9	14	6.4	.0	.0
Columbia, S. C.	347	70	91	29.65	30.03	−.02	75.4	+.9	93	8	85	49	22	66	32	66	63	74	3.03	−.4	8	7.0	ne.	25	ne.	29	7	18	5	5.2	.0	.0
Greenville, S. C.	1,040	70	78	28.94	30.02		72.7	+2.1	93	1	83	46	22	62	32	64	60	73	2.77	−.9	9	5.7	sw.	18	n.	21	5	16	9	6.1	.0	.0
Augusta	182	62	77	29.81	30.00	−.05	76.4	+1.1	95	8	86	49	22	66	35	67	63	74	1.36	−2.0	9	4.8	nw.	21	sw.	15	8	11	11	5.6	.0	.0
Savannah	65	73	152	29.94	30.00	−.03	78.1	+1.9	95	14	87	53	22	69	29	70	68	82	4.25	−1.2	12	8.4	sw.	21	sw.	15	11	9	10	5.2	.0	.0
Jacksonville	43	86	110	29.96	30.01	+.01	77.9	−.4	91	4	86	58	22	70	25	71	69	82	5.91	−1.4	14	6.7	e.	21	sw.	29	7	12	11	5.7	.0	.0
Florida Peninsula							80.8	+0.3										80	6.50	−0.6										5.0		
Key West	21	10	64	29.92	29.94	.00	82.8	+.6	91	17	88	74	24	77	15	76	75	81	3.72	−3.0	18	8.9	e.	32	s.	17	10	15	5	5.0	.0	.0
Miami	25	124	168	29.94	29.97	.00	81.4	+1.3	90	20	87	67	22	76	21	75	72	77	11.30	+3.0	14	8.7	e.	28	se.	7	10	14	6	4.9	.0	.0
Tampa	35	88	197	29.94	29.98	+.01	79.8	−.1	94	4	88	63	21	72	21	72	70	82	5.48	−.9	16	10.2	e.	32	e.	2	7	17	6	5.1	.0	.0
Titusville	43	5	36				79.4	−.4	94	4	89	59	21	70	26	73	71		5.50	−1.4	17		ne.				5	19	6		.0	.0
East Gulf States							76.2	+0.3										74	2.90	−1.3										4.8		
Atlanta [1]	976	5	53	29.01	30.01	−.04	73.8	+1.4	96	8	85	46	22	63	36	64	60	75	3.47	+.5	7	6.7	nw.	27	n.	20	7	15	8	5.7	.0	.0
Macon	370	79	87	29.62	30.01	−.02	75.5	+.7	94	13	86	47	22	65	35	66	62	71	.82	−2.4	4	5.6	nw.	19	ne.	29	9	9	12	5.6	.0	.0
Thomasville	273	49	58	29.72	30.01	.00	76.7	−.1	94	9	86	52	22	67	30	70	67		5.30	+.4	9		e.				13	8	9	5.1	.0	.0
Apalachicola	35	11		29.95	29.99		77.1	−1.4	90	14	83	57	21	71	20	72	70	83	14.45	+6.4	16	8.0	n.	29	se.	27	10	8	12	5.6	.0	.0
Pensacola	56	149	185	29.94	30.00	+.01	77.0	−1.0	88	13	84	56	21	70	23	69	65	73	.54	−4.8	5	10.3	n.	28	ne.	28	15	7	8	4.2	.0	.0
Anniston	741	9					72.8	+1.5	92	5	84	42	22	62	36				1.06	−2.6	6		s.				15	11	4		.0	.0
Birmingham	700	11	48	29.29	30.02	−.01	75.1	+.3	93	2	86	48	22	64	32	65	61	72	1.59	−1.8	2	5.2	nw.	25	se.	26	14	12	4	3.6	.0	.0
Mobile	57	86	161	29.94	30.00	.00	77.5	−.6	94	4	87	52	21	68	31	68	65	76	.97	−4.0	7	7.9	n.	34	e.	10	11	11	8	5.0	.0	.0
Montgomery	218	92	105	29.78	30.02	.00	76.9	+.6	95	1	87	54	22	67	33	67	63	71	.18	−2.8	3	5.7	n.	17	e.	26	11	10	9	4.8	.0	.0
Meridian	375	67	92	29.63	30.01	−.01	75.9	+1.4	95	9	88	47	22	64	37	66	63	76	.89	−2.1	8	4.2	n.	18	ne.	28	12	16	2	3.7	.0	.0
Vicksburg	247	82	102	29.76	30.01	−.01	76.8	+.5	95	9	86	50	21	67	25	67	64	72	.96	−1.9	4	6.7	s.	27	e.	2	15	11	4	4.1	.0	.0
New Orleans	53	76	84	29.95	30.00	+.02	79.4	+.2	93	2	87	61	21	72	21	70	67	72	4.54	−.5	8	5.9	ne.	16	se.	9	11	8	11	5.0	.0	.0
West Gulf States							78.7	+1.6										67	2.37	−1.3										3.7		
Shreveport	249	92	227	29.75	30.01	+.01	79.4	+2.5	98	1	90	54	21	68	29	68	63	66	1.33	−1.5	5	8.7	s.	31	nw.	2	15	13	2	3.6	.0	.0
Bentonville	1,303	12	38	29.69	30.03	+.01	72.8	+3.9	96	1	86	37	20	60	38				1.46	−2.2	5	5.0	s.	15	s.	11	16	12	2		.0	.0
Fort Smith	463	57	82	29.55	30.02	+.01	77.4	+3.4	100	1	89	46	20	65	36	65	59	61	2.13	−.9	5	6.3	e.	21	s.	5	13	14	3	3.8	.0	.0
Little Rock	357	94	102	29.64	30.01	−.02	76.6	+2.5	99	1	87	49	20	66	33	65	59	63	.99	−2.2	7	7.0	sw.	22	ne.	7	11	14	5	4.4	.0	.0
Austin	605	68	90	29.36	29.99		79.4	+1.1	97	27	91	52	22	68	36	68	63	66	2.85	−.6	7	5.8	s.	30	ne.	14	18	11	1	2.5	.0	.0
Brownsville	57	88	96	29.90	29.96		80.8	+.2	96	29	89	66	21	73	25	72	70	78	1.65	−3.9	7	8.1	se.	26	ne.	10	15	11	4	4.1	.0	.0
Corpus Christi	20	11	78	29.96	29.98	+.03	80.6	+.9	93	28	87	66	22	74	23	73	70	76	1.44	−3.0	8	8.7	se.	25	se.	12	12	12	6	4.2	.0	.0
Dallas	512	220	227	29.45	29.99		79.2		97	27	90	50	21	68	32	65	56	51	.51	−2.2	2	9.7	s.	29	nw.	27	17	8	5	3.3	.0	.0
Fort Worth	679	92	110	29.30	30.00	+.01	80.3	+3.4	97	9	92	50	21	69	39				.78	−1.7	3	8.1	s.	24	n.	15	21	6	3	2.0	.0	.0
Galveston	54	106	114	29.94	30.00	+.02	80.2	+.1	90	9	85	67	21	75	17	72	68	70	7.13	+1.6	9	8.4	s.	28	se.	10	12	13	5	4.1	.0	.0
Houston	138	157	190	29.86	30.00		79.0	.0	94	28	88	58	21	70	24				4.25	+.2	8	7.8	s.	22	se.	4	12	11	7	4.6	.0	.0
Palestine	510	64	72	29.49	30.01	+.02	78.2	+1.2	96	27	90	55	21	67	34	66	60	64	1.29	−1.6	3	5.9	s.	22	ne.	10	20	7	3	2.6	.0	.0
Port Arthur	34	59	134	29.96	30.00		79.0		94	1	87	58	21	71	26	70	67	75	5.61	+.8	10	9.5	e.	42	e.	9	13	10	7	4.3	.0	.0
San Antonio	693	111	301	29.28	29.98	+.02	79.6	+.6	96	28	90	59	22	69	30	67	61	62	1.82	−1.2	7	9.5	e.	37	se.	5	12	13	5	4.4	.0	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, September 1938*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	F.	%	In.	In.		Miles								0-10	In.	In.
Ohio Valley and Tennessee							**69.6**	**+0.9**										**74**	**2.95**	**0.0**										**5.4**		
Chattanooga	762	71	214	29.22	30.02	-0.04	74.2	+2.0	95	8	85	46	22	64	33	64	60	70	.32	-2.8	5	6.6	w.	26	w.	14	9	11	10	5.3	0.0	0.0
Knoxville	995	66	84	28.99	30.03	-.03	71.9	+1.3	92	6	82	47	21	62	33	64	61	78	3.13	+.4	9	4.5	ne.	17	w.	14	14	9	7	4.5	.0	.0
Memphis	399	78	86	29.59	30.01	-.02	76.1	+2.5	96	9	85	49	20	67	26	66	62	68	1.38	-1.4	3	6.7	sw.	18	n.	3	13	13	4	4.3	.0	.0
Nashville	546	168	188	29.47	30.05	-.01	71.8	.0	93	8	82	46	20	62	29	64	60	75	3.40	.0	9	6.3	nw.	31	n.	10	10	11	9	5.0	.0	.0
Lexington	989	6					69.8	+1.3	96	6	81	41	20	58	35				2.29	-.8	11		n.				13	7	10		.0	.0
Louisville	525	188	234	29.45	30.03	-.03	71.2	+.7	92	7	80	48	19	63	24	63	59	73	2.99	+.2	8	9.0	sw.	26	sw.	12	15	9	6	4.2	.0	.0
Evansville	431	76	116	29.55	30.01	-.05	72.6	+1.9	95	8	83	47	19	62	27	63	59	70	1.81	-1.5	8	7.3	sw.	25	n.	8	12	10	8	5.0	.0	.0
Indianapolis	822	194	230	29.14	30.02	-.04	68.8	+1.9	91	5	78	45	19	59	29	60	56	70	1.74	-1.7	6	9.7	sw.	25	nw.	22	9	10	11	5.5	.0	.0
Terre Haute	575	63	149	29.38	30.00		71.2		94	5	82	44	19	60	31	62	58	72	1.50	-2.1	6	8.0	sw.	20	nw.	15	12	11	7	4.3	.0	.0
Cincinnati	627	11	51	29.35	30.02	-.05	68.6	+1.5	92	12	78	46	20	59	29	61	58	79	3.80	+1.2	9	6.3	sw.	21	sw.	14	10	9	11	5.8	.0	.0
Columbus	822	90	210	29.15	30.02	-.05	67.4	+.9	91	4	77	46	21	58	32	59	54	70	5.40	+2.8	7	8.1	s.	33	w.	12	6	10	14	6.1	.0	.0
Dayton	899	186	213	29.06	30.00		67.4	+.8	90	4	76	46	30	58	29	60	56	72	4.00	+1.1	6	8.8	sw.	27	sw.	14	8	11	11	5.8	.0	.0
Elkins	1,947	65	83	28.03	30.06	-.02	63.5	+.5	85	6	73	43	26	54	39	58	56	86	4.64	+1.5	15	4.8	se.	19	nw.	21	6	4	20	7.4	.0	.0
Parkersburg	637	77	84	29.34	30.01	-.07	68.0	+.7	90	4	77	44	20	58	31	58	57	76	3.61	+.8	9	5.6	se.	21	nw.	12	9	8	13	5.6	.0	.0
Pittsburgh [1]	1,273	39	54	28.67	30.02	-.06	63.6	-2.8	86	4	73	44	22	54	31	56	56	74	4.30	+1.7	9	9.6	sw.	29	w.	12	6	8	16	6.5	.0	.0
Lower Lake Region							**60.9**	**-2.1**										**76**	**4.61**	**+1.6**										**6.0**		
Buffalo	768	243	280	29.18	30.00	-.06	59.2	-3.2	76	4	66	44	30	52	28	54	51	76	3.57	+.6	12	13.3	nw.	54	sw.	22	7	13	10	5.8	.0	.0
Canton	448	10	61	29.52	29.99		54.9	-4.4	78	4	65	31	9	44	34	51	47	78	5.80	+2.4	13	7.1	sw.	38	sw.	22	10	5	15	6.2	.0	.0
Ithaca	836	77	100	29.12	30.02		57.8	-3.8	82	4	68	38	6	48	36	53	50	80	6.71	+3.6	15	8.6	nw.	29	nw.	21	3	11	16	7.2	.0	.0
Oswego	335	71	85	29.63	30.00	-.06	58.2	-3.0	77	4	66	42	26	51	32	53	50	75	4.91	+2.2	13	9.2	se.	30	nw.	21	7	8	15	6.6	.0	.0
Rochester	523	86	102	29.45	30.02	-.04	59.5	-2.9	80	4	67	42	25	52	29	53	49	72	5.27	+2.8	11	7.7	sw.	30	sw.	4	8	11	11	6.0	.0	.0
Syracuse	596	65	79	29.37	30.02	-.05	58.9	-2.9	80	4	67	40	25	51	36				4.90	+2.2	14	7.3	s.	23	nw.	21	8	10	12	6.3	.0	.0
Erie	714	130	81	29.24	30.00	-.06	61.8	-1.8	82	26	70	47	25	54	29	56	53	79	7.42	+4.0	14	8.2	se.	20	se.	11	9	11	10	5.6	.0	.0
Cleveland	762	267	318	29.19	30.01	-.05	63.4	-.5	83	12	70	46	21	57	24	56	52	71	6.17	+2.8	10	14.2	se.	44	w.	12	8	9	13	5.9	.0	.0
Sandusky	629	5	67	29.33	30.01	-.05	64.8	-.5	92	12	73	44	20	57	30				4.42	+1.5	10	8.1	sw.	18	nw.	21	6	7	17	6.7	.0	.0
Toledo	628	79	87	29.35	30.03	-.03	63.8	-.6	89	12	72	46	19	56	29	57	53	74	2.44	-.4	8	8.8	w.	23	w.	18	11	7	12	5.1	.0	.0
Fort Wayne	857	69	84	29.10	30.02		65.4	.0	90	12	75	43	19	56	30	58	53	73	2.15	-.9	9	8.0	sw.	24	sw.	18	7	15	8	5.3	.0	.0
Detroit [1]	626	5	78	29.34	30.02	-.04	61.8	-1.7	87	12	71	42	25	53	29	55	52	77	1.51	-1.4	8	8.6	nw.	24	sw.	18	10	5	15	5.9	.0	.0
Upper Lake Region							**59.2**	**-0.3**										**80**	**3.44**	**+0.1**										**5.8**		
Alpena	609	13	89	29.36	30.03	.00	57.2	-.4	84	23	65	40	20	49	33	52	49	78	2.90	-.1	9	11.0	nw.	38	se.	18	9	8	13	5.6	.0	.0
Escanaba	612	41	49	29.36	30.02	+.01	57.4	+.3	80	26	66	42	29	49	28	53	50	81	2.68	-.6	11	10.8	n.	30	n.	18	8	8	14	6.3	.0	.0
Grand Rapids	707	70	244	29.25	30.02	-.03	61.7	-1.0	82	4	71	45	16	53	28	56	54	83	2.21	-1.3	12	10.0	e.	39	sw.	18	10	7	13	5.8	.0	.0
Lansing	878	5	90	29.08	30.02		59.6	-1.8	83	4	69	40	25	50	30	54	52	82	1.64	-1.3	10	7.4	n.	25	sw.	18	11	5	14	5.8	.0	.0
Marquette	734	44	69	29.22	30.02	+.02	56.0	-1.5	86	23	64	42	5	48	33	52	48	79	1.87	-1.4	8	7.6	w.	26	sw.	25	6	11	13	6.3	.0	.0
Sault Sainte Marie	614	11	52	29.35	30.05	+.03	54.9	-.6	78	23	63	39	29	47	30	50	48	84	2.55	-1.6	9	7.5	nw.	24	nw.	4	8	6	16	6.0	.0	.0
Chicago	673	7	131	29.29	30.01	-.03	65.0	-.2	89	4	72	42	19	59	26	59	56	80	5.29	+2.2	13	9.3	ne.	25	nw.	12	11	6	13	5.4	.0	.0
Green Bay	617	109	141	29.35	30.02	.00	59.9	-.5	80	23	68	44	29	52	27	54	51	79	6.31	+2.8	15	9.4	ne.	30	n.	18	10	5	15	6.2	.0	.0
Milwaukee	681	97	221	29.28	30.01	-.02	62.8	+.3	86	4	69	45	19	56	27	57	55	80	6.12	+2.8	13	12.4	n.	32	se.	18	12	2	16	5.8	.0	.0
Duluth	1,133	5	47	28.80	30.02	+.04	57.9	+2.8	83	23	67	38	18	49	30	51	48	78	2.85	-.5	6	12.5	ne.	28	nw.	18	11	6	13	5.1	.0	.0
North Dakota							**61.7**	**+4.7**										**62**	**0.95**	**-0.7**										**3.8**		
Moorhead, Minn	940	50	58	29.02	30.03	+.07	61.1	+2.9	91	25	73	33	19	49	45	53	47	66	1.97	-.2	7	7.4	n.	20	n.	26	20	2	8	3.9	.0	.0
Bismarck	1,674	8	57	28.27	30.03	+.09	63.6	+5.5	94	22	76	32	19	51	44	53	45	60	1.11	-.1	3	7.1	e.	22	e.	7	16	6	8	4.0	.0	.0
Devils Lake	1,478	11	44	28.47	30.03	+.09	60.5	+4.6	94	22	74	29	18	47	47	50	42	59	.02	-1.6	1	8.0	e.	20	sw.	10	14	10	6	4.5	.0	.0
Grand Forks	833	12	67				59.5	+3.1	94	25	74	25	20	45	57	51	46		1.14	-.9	5	7.8	n.				12	12	6		.0	.0
Williston	1,878	42	50	28.05	30.01	+.08	63.8	+7.2	93	22	77	33	18	50	44	53	46	61	.49	-.6	2	7.0	se.	27	w.	10	21	2	7	3.0	.0	.0
Upper Mississippi Valley							**67.6**	**+2.3**										**76**	**4.76**	**+1.1**										**4.6**		
Minneapolis and St. Paul, Minn [1]	848	32	61	29.11	30.01	+.02	62.2	+.8	89	23	72	40	18	52	37	55	52	77	3.24	+.1	8	9.0	n.	25	se.	8	12	5	13	5.1	.0	.0
La Crosse	714	11	48	29.25	30.02	+.01	62.6	+.4	87	4	72	43	21	54	31	57	55	85	7.60	+3.6	13	4.5	n.	12	n.	18	12	4	14	5.7	.0	.0
Madison	974	70	78	28.97	30.01	-.02	62.0	-.4	87	4	69	44	19	55	30	57	54	81	10.29	+6.6	13	7.8	n.	29	ne.	17	11	5	14	5.7	.0	.0
Charles City	1,015	10	51	28.94	30.02	+.02	64.2	+3.2	90	9	75	41	19	53	36	58	55	81	8.97	+5.3	10	5.2	se.	15	se.	6	15	8	7	4.3	.0	.0
Davenport	606	66	161	29.36	30.01	-.02	68.4	+2.8	94	7	78	41	19	58	33	61	57	76	5.74	+2.2	12	8.3	ne.	32	n.	9	12	10	8	4.9	.0	.0
Des Moines	861	5	99	29.11	30.00	-.02	69.0	+3.4	97	8	81	39	19	57	37	60	56	70	2.55	-1.1	7	7.7	sw.	29	sw.	10	15	11	4	3.6	.0	.0
Dubuque	699	60	79	29.26	30.01	-.02	65.2	+1.2	92	4	74	44	19	56	35	58	56	79	9.09	+5.1	11	5.4	nw.	18	nw.	11	13	7	10	5.1	.0	.0
Keokuk	614	64	78	29.35	30.00	-.03	70.4	+2.9	96	9	80	40	19	60	34	62	58	73	3.49	-.4	6	5.8	sw.	18	nw.	19	14	6	10	4.8	.0	.0
Cairo	358	87	93	29.63	30.00	-.05	73.2	+1.7	96	9	83	48	20	63	28	65	62	75	.99	-1.9	6	6.8	s.	23	e.	1	15	9	6	4.2	.0	.0
Peoria	609	11	45	29.35	30.02	-.02	68.1	+3.8	94	7	79	38	19	57	38	60	58	79	2.12	-1.9	9	4.7	w.	17	nw.	18	17	8	5	3.5	.0	.0
Springfield, Ill	636	5	191	29.33	30.00	-.05	71.9	+4.3	99	9	83	43	19	61	30	62	57	69	1.98	-1.7	6	9.4	w.	31	se.	9	14	8	8	4.5	.0	.0
St. Louis	568	179	303	29.40	30.00	-.04	74.0	+3.5	98	8	83	45	19	65	28	63	57	63	1.01	-2.4	6	9.1	sw.	24	nw.	17	17	8	5	3.3	.0	.0
Missouri Valley							**70.1**	**+4.0**										**65**	**2.66**	**-0.6**										**3.7**		
Columbia, Mo	784	6	66	29.18	30.00	-.03	71.6	+3.4	99	10	83	40	19	60	37				1.49	-2.9	7	5.8	s.	28	nw.	17	16	6	8	4.1	.0	.0
Kansas City [1]	750	32	45	29.21	30.00	-.02	72.3	+3.4	99	9	84	40	19	60	38	62	57	67	1.84	-2.7	9	7.2	sw.	35	w.	10	17	8	5	3.5	.0	.0
St. Joseph	967	11	49	28.99	30.01		71.7		98	9	84	39	19	60	39	61	55	64	1.24	-2.7	9	6.5	s.	21	nw.	17	19	8	3	2.9	.0	.0
Springfield, Mo	1,324	5	78	28.64	30.02	-.01	72.9	+4.0	96	10	84	44	21	62	37	61	56	65	1.81	-1.7	8	6.8	s.	22	w.	13	15	10	5	3.4	.0	.0
Topeka	987	65	87	28.97	30.01		72.8	+4.1	100	10	86	38	19	60	40	61	55	61	.37	-3.4	4	7.8	s.	23	nw.	14	18	9	3	3.3	.0	.0
Lincoln	1,189	11	81	28.75	30.00	+.01	71.3	+4.9	98	9	83	38	19	60	37	60	54	64	2.94	.0	6	7.9	s.	32	s.	5	15	10	5	4.0	.0	.0
Omaha [1]	982	31	44	28.97	30.01	+.01	70.4	+3.6	98	9	83	38	20	58	39	61	57	72	4.84	+1.6	8	7.8	s.	32	sw.	5	16	6	8	3.9	.0	.0
Valentine	2,598	47	54	27.35	30.04	+.08	66.0	+3.5	95	9	80	35	18	52	48	56	49	64	1.23	-.1	7	6.9	n.	25	sw.	25	14	9	7	4.2	.0	.0
Sioux City	1,138	64	106	28.80	30.00	+.02	68.3	+4.9	97	9	80	35	19	56	43	59	54	66	7.94	+4.9	9	7.2	s.	25	nw.	18	15	8	7	4.1	.0	.0
Huron	1,307	59	74	28.65	30.04	+.08	65.7	+4.4	92	22	78	33	1	53	42	56	49	64	2.95	+1.4	6	7.5	n.	36	w.	9	16	10	4	3.5	.0	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, September 1938*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							**64.0**	**+7.1**										**56**	**1.41**	**+0.2**										**3.5**		
Havre	2,507	11	67	27.40	30.01	+0.07	65.6	+9.2	92	22	82	42	19	49	47	53	44	55	1.34	.0	6	7.2	e.	28	e.	5	21	7	2	2.5	0.0	0.0
Helena	4,124	85	111	25.88	30.00	+.03	64.2	+7.6	86	18	78	44	12	50	38	50	38	43	.72	−.5	5	7.2	sw.	37	s.	4	18	6	6	3.3	.0	.0
Missoula	3,263	80	91	----	----	----	66.2	+10.8	93	3	82	41	27	51	43	----	----	----	.66	−.8	7	6.1	s.	38	sw.	29	18	9	3	3.0	.0	.0
Kalispell	2,973	48	56	27.00	30.01	+.05	62.4	+8.9	91	1	77	36	6	48	37	52	44	58	1.14	−.1	8	5.3	nw.	27	sw.	29	19	4	7	3.3	.0	.0
Miles City	2,371	48	55	27.54	29.99	+.04	67.6	+6.4	95	22	81	46	18	54	43	55	45	51	.34	−.7	5	4.9	s.	22	nw.	9	16	10	4	3.6	.0	.0
Rapid City	3,259	50	58	26.71	30.03	+.07	65.9	+5.5	90	29	78	39	19	54	46	55	46	54	1.29	+.1	8	6.7	w.	21	s.	30	18	5	7	3.5	.0	.0
Cheyenne [1]	6,144	5	39	24.10	30.04	+.08	60.0	+3.0	83	29	74	36	19	46	44	50	44	65	3.33	+2.1	8	8.7	w.	34	sw.	9	17	7	6	3.5	.0	.0
Lander	5,352	60	68	24.78	30.02	+.06	62.2	+6.5	84	19	77	40	28	48	42	49	38	50	.65	−.3	5	4.6	sw.	25	sw.	8	16	8	6	4.1	.0	.0
Sheridan	3,790	10	47	26.18	30.04	----	62.6	----	92	21	81	33	19	44	55	50	43	59	.04	−1.2	2	4.1	s.	16	se.	1	15	10	5	3.8	.0	.0
Yellowstone Park	6,241	12	46	24.04	30.13	+.16	57.8	+7.7	80	21	73	35	17	42	44	45	36	52	.54	−.7	8	6.5	sw.	26	w.	29	13	14	3	3.6	.0	.0
North Platte	2,821	11	51	27.14	30.03	+.06	67.7	+5.6	94	9	81	37	19	54	46	57	52	68	5.41	+4.1	10	6.0	w.	20	sw.	7	17	4	9	4.2	.0	.0
Middle Slope							**71.5**	**+3.4**										**58**	**2.22**	**+0.1**										**3.1**		
Denver	5,292	106	113	24.86	30.05	+.09	65.4	+2.5	86	9	76	48	19	54	31	52	43	55	3.42	+2.4	8	7.0	s.	24	n.	9	18	5	7	3.7	.0	.0
Pueblo	4,685	80	86	25.40	30.02	+.06	67.4	+2.8	89	9	81	44	30	54	42	55	46	56	1.80	+1.0	5	6.1	nw.	28	w.	7	17	8	5	3.5	.0	.0
Concordia	1,392	50	58	28.56	30.01	+.02	72.2	+3.9	98	10	85	36	19	59	40	60	54	62	1.52	−1.1	7	7.5	s.	21	s.	5	18	9	3	2.9	.0	.0
Dodge City	2,509	10	86	27.44	30.00	+.02	73.0	+3.6	94	23	86	43	19	60	39	59	52	58	2.73	+.8	8	10.0	s.	33	sw.	5	20	4	6	3.0	.0	.0
Wichita	1,358	85	93	28.59	30.00	.00	74.2	+3.6	96	30	85	43	19	63	35	61	54	56	2.62	−.5	7	8.7	se.	25	n.	17	24	3	3	2.1	.0	.0
Oklahoma City	1,214	10	47	28.73	29.99	.00	76.6	+3.8	99	1	88	47	20	65	37	63	56	59	1.23	−1.8	3	7.5	s.	26	s.	2	18	6	6	3.4	.0	.0
Southern Slope							**76.2**	**+2.6**										**53**	**0.93**	**−1.6**										**3.3**		
Abilene	1,738	10	56	28.21	29.98	+.02	79.0	+3.7	97	9	92	54	17	66	36	62	53	48	.29	−2.4	4	8.1	s.	18	n.	16	18	8	4	3.3	.0	.0
Amarillo	3,676	10	49	26.35	30.01	+.05	73.6	+4.3	94	26	86	53	20	61	38	58	49	51	1.62	−.7	8	7.9	se.	19	se.	3	20	6	4	3.0	.0	.0
Del Rio	960	63	71	28.96	29.93	−.01	80.4	+1.2	98	10	91	60	18	70	32	66	59	55	.36	−2.6	3	8.1	se.	24	n.	14	14	11	5	3.7	.0	.0
Roswell	3,566	75	85	26.44	29.99	+.07	71.6	+1.3	91	13	85	52	25	58	38	59	51	59	1.45	−.7	8	6.0	s.	26	s.	6	18	6	6	3.3	.0	.0
Southern Plateau							**72.5**	**+2.1**										**52**	**1.08**	**+0.2**										**3.1**		
El Paso	3,778	82	101	26.23	29.94	+.06	73.8	−.1	91	25	86	55	24	62	36	60	52	54	2.31	+1.1	7	6.2	e.	26	e.	6	23	6	1	2.1	.0	.0
Albuquerque [1]	4,972	5	30	25.15	29.97	----	67.4	−.5	86	29	80	49	25	54	36	55	48	61	2.36	+1.5	8	6.4	n.	35	nw.	16	17	6	7	3.6	.0	.0
Santa Fe	7,013	38	53	23.40	30.03	+.10	61.7	+.8	79	26	73	44	17	51	29	49	41	56	1.48	.0	11	5.0	e.	15	ne.	23	12	9	9	5.3	.0	.0
Flagstaff	6,907	10	59	23.47	29.93	+.04	59.8	+4.3	80	9	76	38	19	44	39	----	----	56	.97	−.5	9	6.6	nw.	24	nw.	23	4	21	5	----	.0	.0
Phoenix	1,107	39	51	28.69	29.81	.00	86.8	+4.1	107	9	101	67	13	72	38	66	54	38	T	−.8	0	5.5	e.	30	nw.	10	20	6	4	2.9	.0	.0
Yuma	141	9	54	29.64	29.78	.00	87.4	+3.7	108	13	103	64	8	72	38	70	60	47	.35	.0	2	4.4	s.	26	s.	30	25	4	1	1.4	.0	.0
Independence	3,957	5	26	25.99	29.95	+.09	70.4	+2.4	94	3	86	48	7	55	40	53	36	----	.08	.0	1	----	s.	----	----	----	19	7	4	----	.0	.0
Middle Plateau							**65.2**	**+3.7**										**42**	**0.96**	**+0.4**										**3.2**		
Reno	4,527	61	76	25.50	29.96	+.01	65.2	+4.7	91	15	82	40	29	49	42	50	38	44	.07	−.2	2	5.5	w.	23	w.	4	23	6	1	1.8	.0	.0
Tonopah	6,090	12	20	----	----	----	67.8	----	86	2	79	40	6	57	38	49	34	31	T	----	0	7.8	se.	17	se.	29	----	----	----	----	.0	.0
Winnemucca	4,344	18	56	25.64	29.97	+.04	64.4	+5.2	95	3	84	34	7	44	54	48	33	38	.17	−.2	1	6.7	ne.	22	s.	27	20	5	5	2.9	.0	.0
Modena	5,473	10	43	24.69	29.95	+.03	63.0	+3.0	85	3	80	40	26	46	44	49	38	48	1.17	+.4	6	9.0	w.	32	s.	29	13	10	7	4.2	.0	.0
Salt Lake City [1]	4,227	32	46	25.77	29.95	.00	68.7	----	90	4	84	47	11	54	37	53	40	40	.09	----	3	9.6	se.	31	sw.	22	16	12	2	3.4	.0	.0
Grand Junction	4,602	60	68	25.47	30.01	+.06	68.2	+2.0	87	28	81	49	13	56	33	55	46	52	2.41	+1.5	6	5.9	se.	27	nw.	10	14	11	5	3.8	.0	.0
Northern Plateau							**68.2**	**+7.8**										**44**	**0.28**	**−0.4**										**3.0**		
Baker	3,471	36	54	26.49	30.01	+.02	63.4	+7.4	94	2	80	37	9	47	44	51	41	51	.73	.0	6	5.8	s.	22	s.	23	17	7	6	3.5	.0	.0
Boise	2,739	79	87	27.17	29.98	+.01	68.6	+6.7	96	3	83	42	9	54	38	54	42	44	.34	−.2	3	4.9	nw.	17	se.	23	22	4	4	2.3	.0	.0
Pocatello [1]	4,441	5	31	25.54	29.99	+.03	65.4	----	90	18	83	37	11	48	47	50	36	39	.02	----	1	7.3	sw.	26	sw.	7	23	5	2	2.5	.0	.0
Spokane	1,929	101	110	27.97	29.98	.00	67.8	+8.6	98	18	83	45	12	53	41	54	43	47	.09	−.8	6	4.7	s.	21	sw.	23	20	3	7	3.2	.0	.0
Walla Walla	991	57	65	28.91	29.96	−.04	71.2	+7.4	98	1	84	51	25	59	35	56	45	41	.15	−.8	4	4.8	s.	18	w.	4	18	10	2	3.1	.0	.0
Yakima	1,076	58	67	28.84	29.97	----	69.8	+8.7	96	2	84	45	30	56	35	56	45	45	.09	−.4	3	5.6	nw.	23	nw.	18	16	10	4	3.3	.0	.0
North Pacific Coast Region							**63.0**	**+4.0**										**74**	**1.38**	**−0.8**										**5.3**		
North Head	211	11	56	29.82	30.04	+.01	57.8	+1.3	74	13	62	49	14	54	23	56	55	94	3.12	+.1	13	11.9	n.	39	s.	19	5	8	17	7.1	.0	.0
Seattle	125	90	321	29.89	30.02	+.01	63.4	+5.3	87	14	72	50	16	55	32	58	54	73	.48	−1.3	7	6.6	n.	21	sw.	4	11	8	11	5.2	.0	.0
Tacoma	194	172	201	29.83	30.03	+.01	61.7	+4.4	86	14	70	47	27	54	32	----	----	----	.48	−1.6	9	6.2	n.	23	sw.	4	6	13	11	6.0	.0	.0
Tatoosh Island	86	10	54	29.94	30.04	+.03	55.2	+2.2	67	13	60	46	17	51	19	54	53	91	1.95	−2.7	11	9.0	s.	35	e.	14	8	6	16	6.5	.0	.0
Medford	1,329	29	58	28.59	29.97	----	67.9	+4.6	102	16	85	44	30	51	50	56	46	55	.58	+.1	5	----	nw.	----	----	----	19	4	7	3.5	.0	.0
Portland Oreg	153	68	106	29.84	30.00	−.03	67.5	+5.8	95	17	78	53	20	57	36	60	54	67	1.38	−.6	8	5.4	nw.	15	s.	4	10	13	7	4.7	.0	.0
Roseburg	510	45	76	29.45	29.99	−.03	67.2	+4.3	96	13	81	48	26	53	44	58	51	62	1.64	+.4	5	3.9	nw.	21	sw.	28	14	8	8	4.0	.0	.0
Middle Pacific Coast Region							**67.0**	**+2.1**										**64**	**0.90**	**+0.2**										**4.2**		
Eureka	60	72	88	29.96	30.03	+.02	57.0	+1.1	68	28	62	48	13	52	16	54	53	90	1.74	+.7	7	5.4	n.	18	n.	5	3	10	17	7.4	.0	.0
Redding [1]	722	20	34				76.7	+3.2	105	14	88	56	30	65	34	58	42	34	1.39	+.6	2	8.0	nw.	24	nw.	4	17	7	6	3.1	.0	.0
Sacramento	66	92	115	29.83	29.90	+.01	73.1	+3.8	101	14	88	54	20	59	39	60	50	51	.30	−.1	2	6.1	s.	17	s.	16	23	5	2	2.0	.0	.0
San Francisco	155	112	132	29.78	29.94	.00	61.2	+.3	89	9	68	51	22	54	35	56	54	83	.15	−.3	1	9.0	w.	27	w.	3	8	19	3	4.5	.0	.0
South Pacific Coast Region							**73.7**	**+3.9**										**64**	**0.05**	**−0.1**										**3.1**		
Fresno	327	97	105	29.54	29.88	+.01	76.8	+3.4	102	15	92	55	23	62	34	61	49	44	.13	−.1	1	6.2	nw.	16	nw.	3	22	2	6	2.4	.0	.0
Los Angeles	338	159	191	29.53	29.89	+.01	74.0	+5.0	94	13	84	57	11	64	29	63	58	67	.01	−.2	1	5.2	sw.	18	w.	17	21	5	4	2.7	.0	.0
San Diego	87	62	70	29.79	29.88	−.01	70.4	+3.3	88	26	77	58	12	64	27	65	62	80	.00	−.1	0	6.5	nw.	21	nw.	26	15	9	6	4.3	.0	.0
West Indies																																
San Juan, P. R.	82	9	54	29.86	29.94	----	80.5	.0	91	14	85	71	30	76	15	----	----	----	5.57	−.3	18	10.0	e.	26	e.	24	7	19	4	4.9	.0	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, September 1938*—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air												Precipitation			Wind									
																								Maximum velocity							
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Total	Departure from normal	Days with 0.01 inch or more	Average hourly velocity	Prevailing direction	Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Panama Canal																																
Balboa Heights	118	6	92	------	[3] 29.84	+0.02	79.4	−0.4	89	23	85	71	14	74	16	----	----	[2] 86	8.23	+0.1	20	4.8	nw.	18	se.	14	0	23	7	6.6	0.0	0.0
Cristobal	36	6	97	------	[3] 29.84	+.01	81.1	+.7	90	26	86	74	20	76	15	76	75	[2] 85	10.50	−2.0	19	5.7	se.	21	se.	6	0	12	18	7.7	.0	.0
Alaska																																
Fairbanks	454	11	87	[3] 29.11	[3] 29.61	------	49.3	+5.9	73	14	59	28	20	39	33	46	42	75	.58	−.8	12	6.3	s.	27	s.	15	0	8	22	8.2	.7	T
Juneau	80	96	116	[3] 29.80	[3] 29.89	------	54.1	+3.9	77	1	60	41	17	49	29	51	48	82	13.23	+2.8	24	7.8	se.	27	s.	20	2	1	27	8.9	.0	.0
Nome	22	5	32	------	[3] 29.61	------	41.8	+.2	61	13	50	26	18	34	24	----	----	76	2.09	−.7	13	8.9	n.	27	sw.	29	6	5	19	----	T	.0
Hawaiian Islands																																
Honolulu	38	86	100	29.93	29.97	------	78.6	+.4	85	8	83	71	15	74	14	71	67	69	.33	−1.0	12	8.8	e.	22	e.	19	13	15	2	3.8	.0	.0
Panama Canal																Late reports for August 1938																
Balboa Heights	118	6	92	------	[3] 29.84	+.01	79.4	−1.8	89	21	86	70	17	73	16	----	----	[2] 86	11.82	+4.0	21	4.9	nw.	20	s.	10	0	18	13	7.0	.0	.0
Cristobal	36	6	97	------	[3] 29.84	.00	80.6	+.4	90	30	86	73	11	75	15	75	74	[2] 85	22.32	+7.0	30	6.2	w.	24	w.	16	1	6	24	8.3	.0	.0

[1] Observations taken at airport. [2] Observations taken bihourly. [3] Pressure not reduced to a mean of 24 hours.

TABLE 3.—*Data furnished by the Canadian Meteorological Service, September 1938*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max.+ mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	In.	In.	In.	° F.	° F.	° F.	° F.	° F.	° F.	In.	In.	In.
Cape Race, Newfoundland	99	------	------	------	------	------	------	------	------	------	------	------	------
Sydney, Cape Breton Island	48	29.88	30.01	−0.03	59.4	+2.4	68.0	50.9	81	40	5.79	+2.42	0.0
Halifax, Nova Scotia	88	29.77	30.03	−.02	59.7	+1.4	66.1	53.3	75	46	8.24	+4.50	.0
Yarmouth, Nova Scotia	65	29.91	30.02	−.04	57.6	+1.6	65.5	49.6	81	39	5.91	+2.40	.0
Charlottetown, Prince Edward Island	38	29.93	30.02	.00	58.2	+1.3	64.9	51.4	80	40	4.24	+.55	.0
Chatham, New Brunswick	28	29.85	29.97	.00	55.4	−1.0	64.7	46.1	81	34	3.04	+.01	.0
Father Point, Quebec	20	29.91	29.93	−.05	48.2	−1.5	55.2	41.1	70	29	3.30	+.32	.0
Quebec, Quebec	296	29.66	29.98	−.04	54.8	−.8	62.0	47.7	73	37	5.54	+1.52	.0
Doucet, Quebec	1,236	28.68	30.02	−.01	48.5	+.1	58.3	38.6	73	21	4.24	−.11	.0
Montreal, Quebec	187	------	------	------	------	------	------	------	------	------	------	------	------
Ottawa, Ontario	236	29.74	30.00	−.03	54.2	−3.8	63.4	45.0	74	33	3.90	+1.10	.0
Kingston, Ontario	285	29.68	30.00	−.05	58.3	−1.7	65.3	51.3	81	40	5.57	+2.77	.0
Toronto, Ontario	379	29.60	30.02	−.03	58.9	−1.5	67.2	50.7	82	42	3.98	+1.02	.0
Cochrane, Ontario	930	29.97	29.99	−.03	50.8	−.6	60.0	41.6	80	31	2.15	−.92	.0
White River, Ontario	1,244	28.74	30.10	+.11	49.2	−.8	61.5	36.9	78	23	2.21	−.82	.0
London, Ontario	808	29.15	30.03	−.03	57.3	−3.2	67.1	47.5	80	37	2.57	−.31	.0
Southampton, Ontario	656	29.30	30.02	−.02	55.8	−3.4	65.0	46.5	79	36	2.50	−.38	.0
Parry Sound, Ontario	688	29.32	30.02	−.01	55.8	−1.6	64.8	46.9	76	38	2.76	−.85	.0
Port Arthur, Ontario	644	29.32	30.04	+.06	52.6	−.6	63.0	42.2	82	32	1.25	−2.13	.0
Winnipeg, Manitoba	760	29.18	30.04	+.07	59.4	+5.2	73.3	45.4	90	28	.24	−2.02	.0
Minnedosa, Manitoba	1,690	28.24	30.04	+.10	57.8	+5.8	72.7	42.8	89	27	.28	−1.32	.0
Le Pas, Manitoba	860	29.05	30.01	+.11	58.2	+9.0	71.2	45.2	84	28	.40	−1.41	.0
Qu'Appelle, Saskatchewan	2,115	27.78	30.04	+.08	61.1	+9.2	74.9	47.3	94	31	.89	−.74	.0
Moose Jaw, Saskatchewan	1,759	28.05	30.01	+.09	63.1	+9.6	77.6	48.7	95	36	1.04	−.23	.0
Swift Current, Saskatchewan	2,392	27.22	30.00	+.05	63.2	+9.9	76.5	49.9	89	39	1.72	+.45	.0
Medicine Hat, Alberta	2,365	27.52	30.00	+.07	64.3	+8.3	80.0	48.6	91	39	2.36	+1.20	.0
Calgary, Alberta	3,540	26.38	30.00	+.04	60.8	+10.3	76.7	44.8	88	35	.82	−.71	.0
Banff, Alberta	4,521	------	------	------	------	------	------	------	------	------	------	------	------
Prince Albert, Saskatchewan	1,450	28.46	30.00	+.06	59.6	+9.4	71.7	47.5	84	34	1.30	−.25	.0
Battleford, Saskatchewan	1,592	28.26	29.98	+.04	61.6	+10.1	76.3	46.8	90	33	3.99	+2.66	.0
Edmonton, Alberta	2,150	27.70	30.00	+.09	59.9	+9.7	75.1	44.7	90	36	.21	−1.10	.0
Kamloops, British Columbia	1,262	28.70	30.04	+.06	63.4	+4.8	75.5	51.4	89	45	1.41	+.59	.0
Victoria, British Columbia	230	29.80	30.05	+.06	58.8	+2.8	66.0	51.7	80	49	1.62	−.03	.0
Barkerville, British Columbia	4,180	------	------	------	------	------	------	------	------	------	------	------	------
Estevan Point, British Columbia	20	------	------	------	------	------	------	------	------	------	------	------	------
Prince Rupert, British Columbia	170	29.82	30.00	+.03	59.7	+6.1	62.5	56.9	78	41	8.33	+.54	.0
St. George's, Bermuda	158	------	30.07	.00	79.5	+1.7	85.3	73.6	90	68	4.51	−1.05	.0
LATE REPORTS FOR AUGUST 1938													
Cape Race, Newfoundland	99	------	------	------	60.4	+3.8	66.4	54.4	78	47	5.30	+1.29	0.0
Father Point, Quebec	20	29.85	29.88	−0.04	59.6	+3.9	65.6	53.5	76	40	5.53	+2.42	.0
Winnipeg, Manitoba	760	29.03	29.88	−.08	67.2	+3.2	80.1	54.2	92	41	1.74	−.60	.0
Kamloops, British Columbia	1,262	28.68	30.00	+.08	65.3	−3.0	77.8	52.8	86	46	2.94	+1.86	.0
Estevan Point, British Columbia	20	30.09	30.11	+.07	55.8	−1.0	61.0	50.6	65	43	2.07	−1.21	.0

TABLE 4.—*Severe local storms, September 1938*

[Compiled by Mary O. Souder from reports submitted by Weather Bureau officials]

[The table herewith contains such data as has been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the United States Yearbook]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Albuquerque, N. Mex	Aug. 31–Sept. 1					Rain	Underpasses flooded; streets washed out; adobe houses undermined; many cellars flooded.
Diamond, Mo., vicinity of	1		880	0		Tornado	Trees blown down; roofs damaged; windows blown out; 1 person injured. Storm moved from northwest to southeast over a path 4 miles long.
Oklahoma City, Okla	2				$1,500	Wind and rain	Property damaged in southwest portion of the city.
Colorado, Fort Collins to Pueblo and vicinities.	2–3			7		Heavy rain and flood.	Much property damage; loss to crops.
Custer and Fall River Counties, S. Dak.	4	7–10 p. m.		2	54,000	do	Damage to railroad property, buildings, bridges, highways, and farms; loss to livestock.
Pondora County, Mont	5	2 p. m.	[1]3		60,000	Hail	Loss to standing wheat, mustard, and sugar beets; path 22 miles long.
Yellowstone County, Mont., western portion.	5	3:30 p. m.	[1]1		1,200	do	Loss to crops; path 2 miles long.
Phillips County, Mont., southern portion.	5	6–7 p. m.				Heavy hail and rain.	Considerable damage to gardens; hay lands flooded.
Subiaco, Ark	5				2,500	Electrical	Farmhouse destroyed by lightning.
Big Horn County, Mont	5		[1]4		5,000	Hail	Loss to sugar beets; path 10 miles long.
Landeau to Trail City, S. Dak	5			3	56,500	Torrential rain and flood.	7 miles of telegraph line destroyed; several bridges, buildings, farm machinery and a mile of track of a branch line of the Milwaukee R. R. washed out.
Pondora County, Mont	6	2 a. m.	[1]39		40,000	Hail	Loss to crops; path 30 miles long.
Jerome to Flagstaff, Ariz	6				550	Rain	A 300-ton landslide caused damage to highway.
Minnesota, extreme southeastern counties.	6–10			3	100,000	Rain and flood	Several short stretches of railroad tracks, some bridges and small buildings washed out; many basements flooded; number of houses and stores partially submerged; highways under water; poultry and hogs drowned; communication systems disrupted. In portions of Winona and Wabasha Counties 50 percent of late crops ruined. Greatest damage occurred in the Alba-Beaver area.
Toole County, Mont., northern portion.	7	3–4 a. m.	[1]3			Heavy hail	Loss of crops; path 10 miles long. This storm reported to have been the second worst hailstorm in 36 years.
Fergus County, Mont., northern and western portions.	7	3:30–10 p. m.	[1]6		17,500	Hail	Loss to crops; property damage, $5,000; path 60 miles long.
Salem, S. Dak., 6 miles south	7	7 p. m.	227–1,760	0	30,000	Tornado	Telephone lines and several farm buildings wrecked; house twisted on its foundation. Property damage, $25,000 crop loss, $5,000 path from 6 to 8 miles long.
Freeport, Ill	7				2,200	Electrical	17 cows killed by lightning.
Pana, Ill	7				1,000	Wind	Trees and several greenhouses damaged.
Nobles, Rock, Pipestone, Cottonwood, and Jackson Counties, Minn.	7–8				16,000	Rain and flood	Heavy to excessive rains caused a number of washouts on the Chicago, St. Paul, Minneapolis and Omaha Railroads between Worthington, Minn., and Sioux Falls, S. Dak. Many basements flooded in Worthington where 4.42 inches of rain occurred within a few hours with some highways under water. Crop loss, $5,000.
Blaine County, Mont	8	5:30 p. m.	[1]5		25,000	Heavy hail	Loss to wheat and hay; path 10 miles long.
Yellowstone County, Mont	8	do	[1]2		5,000	do	Loss to beans and hay; path 5 miles long.
Wolsey, S. Dak	9	9:30 p. m.	[1]1		10,000	Wind	Several barns, garage, and outbuildings wrecked; roofs damaged; windows broken.
Canton, Ill.[2]	9	P. m.				Heavy rain	City in darkness; in some sections water 3 feet deep in streets.
Chicago, Ill	9					Electrical	Man and horse killed; street car struck by lightning and 9 persons injured.
Phoenix to Tucson, Ariz	10	A. m.				Duststorm	Visibility in some sections reduced to 880 yards.
Wilder, Kans., vicinity of	10	2:30 p. m.	200		800	Wind	Damage to small buildings and telephone lines; path 1 mile long.
McLouth, Kans., vicinity of	10	4 p. m.	2,640		20,000	Tornadic winds	Tornado cloud observed, but did not reach the ground. Damage from side winds only. Loss to crops, $9,000, included in the estimate; path 3 miles long.
Fremont County, Iowa	10	5 p. m.		1	15,000	Wind	Property damage, $5,000; loss to crops, $10,000. Man fatally injured.
Charlotte, Iowa	11	1:50 a. m.				Thunderstorm and hail.	Excessive rain caused small streams to overflow, flooding many acres of land. Hail caused loss to corn crop. Bandstand in city park wrecked; many trees, telephone and telegraph poles down; electric service interrupted until noon.
San Pedro Valley, Ariz., upper portion.	11				905	Heavy rain	Damage to railroad property.
Fort Cobb, Okla	12	6 p. m.	[1]2		1,800	Wind	Loss to crops, $800; property damage, $1,000; path 3 miles long.
Rock Island and Mercer Counties, Ill.[2]	13	4 p. m.				Tornadic winds and rain.	Property damaged.
Suffolk, Va	13	5:05-5:20 p. m.			20,000	Thunderstorm	Warehouse struck by lightning and destroyed.
Clinton, Iowa	13				25,000	Heavy rain and wind.	Several blocks in northern section of the city flooded and tons of silt, rock and debris, carried down from side streets on to main highways. Property damage includes city streets, sewer system and bridges.
Jamestown, N. Y., and vicinity	13–14					Heavy rains	Highways flooded and washed out; bridge destroyed; many cellars flooded.
The following is a brief summary of the tropical hurricane, Sept. 21, 1938:							
Norfolk, Va., and vicinity	21				1,000	Tropical hurricane	Loss to bean crop and shocked hay.
New Jersey	21	1:10 p. m.		3	200,000	do	The center of this storm passed about 75 miles east of Atlantic City. Trees uprooted; property damaged.
Long Island and eastern New York.	21			69	5,220,000	Tropical storm with hurricane winds and tidal wave.	On Long Island many lives were lost with millions in property damage. Much loss to apple crop in eastern New York. In the Albany district, estimated damage from floods, wind and heavy rain, $5,220,000.
Connecticut	21	P. m.		85	100,000,000	Tropical hurricane and flood.	The center of the storm in Connecticut passed a short distance west of New Haven. Here 17 deaths and damage amounting to $3,000,000 occurred. 3,600 trees blown down and 415 buildings damaged. Much loss to Public Utilities. East of New Haven, many cottages were washed away and a number of persons along the Connecticut coast drowned.
Rhode Island	21	1–4:10 p. m.		380	100,000,000	Tropical hurricane and tidal wave.	76 persons missing. 2,380 houses totally destroyed; 5,480 houses damaged. The totally destroyed houses and cottages were affected principally by the accompanying tidal wave.

[1] Miles instead of yards.
[2] From press reports.

TABLE 4.—*Severe local storms, September 1938*—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
The following is a brief summary of the tropical hurricane, Sept. 2., 1938—Continued.							
Boston, Mass., and vicinity	21			99	$3,000,000	Hurricane	Damage mostly from falling trees on wires. Storm-wave caused greatest material damage and loss of life in Narragansett Bay, Buzzards Bay, and parts of the southern Massachusetts shore. Almost total loss of remaining crops. In Nantucket abnormally high tide and heavy swells on the ocean side of the island did considerable damage to shore property.
New Hampshire	21	3:30-8:30 p.m.		14	22,000,000	Tropical hurricane.	At 9:30 a. m., many houses and industrial establishments in Concord, Manchester, Nashua, Lowell and Lawrence were under water due to previous heavy rain. Peak of the storm at 5:45 p. m. Widespread damage throughout the State with greatest damage in the southern and central portions. Thousands of large trees uprooted. Much property damage. Principal loss incurred by Public Utilities.
Vermont	21			7	15,000,000	Wind and rain	Storm of tropical origin caused damage over all of Vermont. Poles, wires, and trees down. Loss to farmers, crops and public utilities. In this State, mostly, maple sugar growth will not recover for 20 to 25 years.
Maine	21				135,000	Hurricane	Loss to Cumberland Power & Light Co., $100,000, to Boston & Maine R. R., $25,000; loss to trees, $10,000.
Buffalo, N. Y	22	10:53 a. m.				Wind and rain	Maximum wind velocity of 54 miles from the southwest recorded. Streets flooded making motor traffic difficult. Small property damage. On the Lake, several small boats were driven ashore or tipped over. Large vessels unable to leave port. This storm is what was left of the destructive hurricane that caused great damage and loss of life the previous day on and near the North Atlantic coast, particularly Connecticut, Long Island, Rhode Island, and Massachusetts.
Charleston, S. C	29	7:50 a. m.		32	2,000,000	2 tornadoes	Several hundred persons injured; much property damage. This storm one of the most destructive occurrences of its kind in the history of the State. A more detailed report will appear elsewhere in this issue of the REVIEW.
Sanders, Lake, and Flathead Counties, Mont.	29	5-7 p. m.				Straight-line wind.	Winds, in some sections, accompanied by severe dust and followed by rain. Much commercial timber blown down, trees falling on highways interrupting traffic. Electric service dalayed for several hours when poles and wires blew down. Minor property damage.
New Orleans, La., and vicinity	29				700	Electrical	2 buildings struck by lightning; electric service interrupted in several localities.
Kalispell, Mont., vicinity of	29					Wind	Considerable damage to small farm buildings, telephone and power lines. Many trees blown down; much loss to fruit crop.
Wilmington, N. C	29					Heavy rain	Cellars and streets flooded, the latter to the depth of 5 feet in some sections.

[2] A more detailed report appears elsewhere in this issue of the REVIEW.

U. S. GOVERNMENT PRINTING OFFICE: 1938

Chart I. Departure (°F.) of the Mean Temperature from the Normal, September 1938

Chart I. Departure (°F.) of the Mean Temperature from the Normal, September 1938

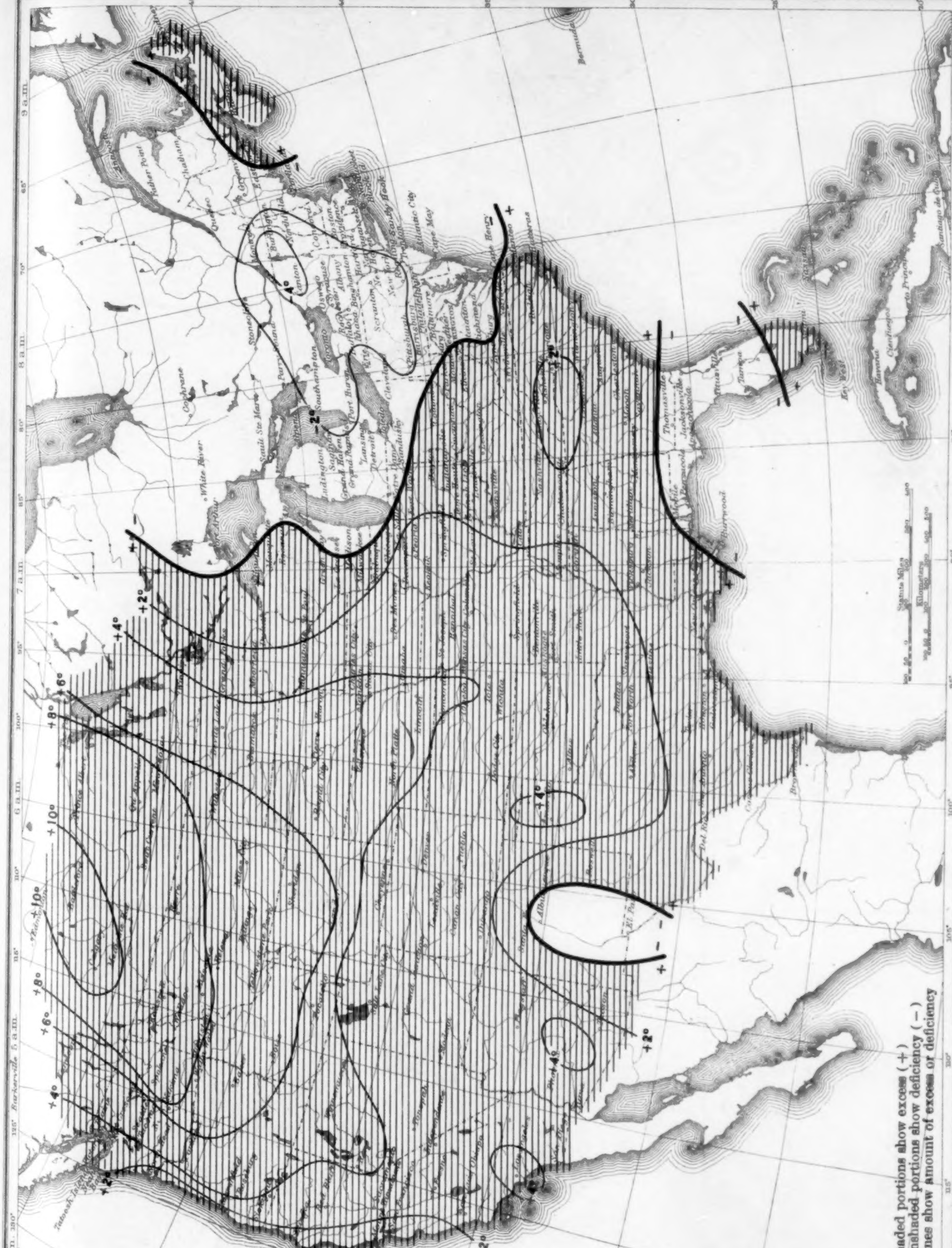
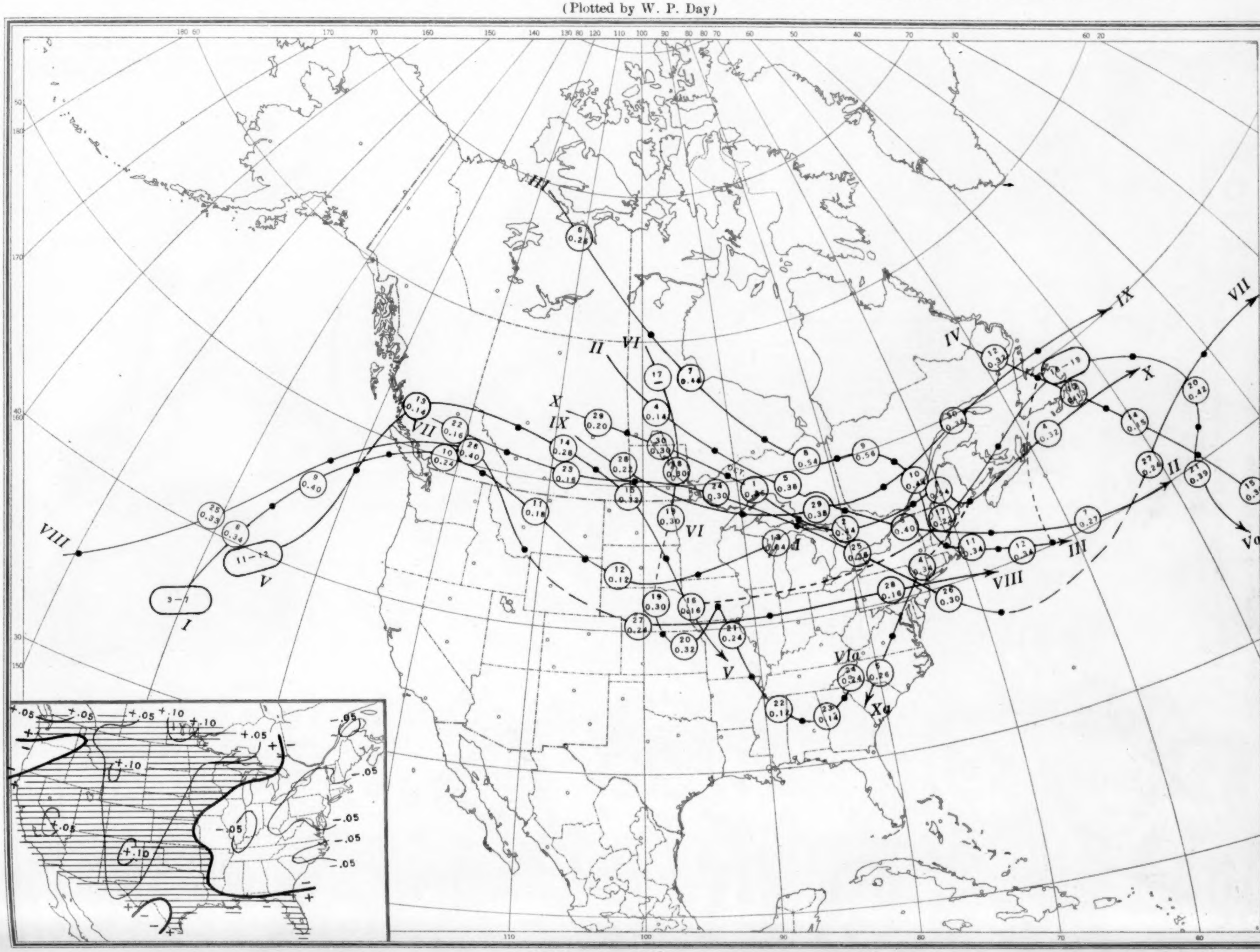


Chart II. Tracks of Centers of Anticyclones, September 1938. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by W. P. Day)

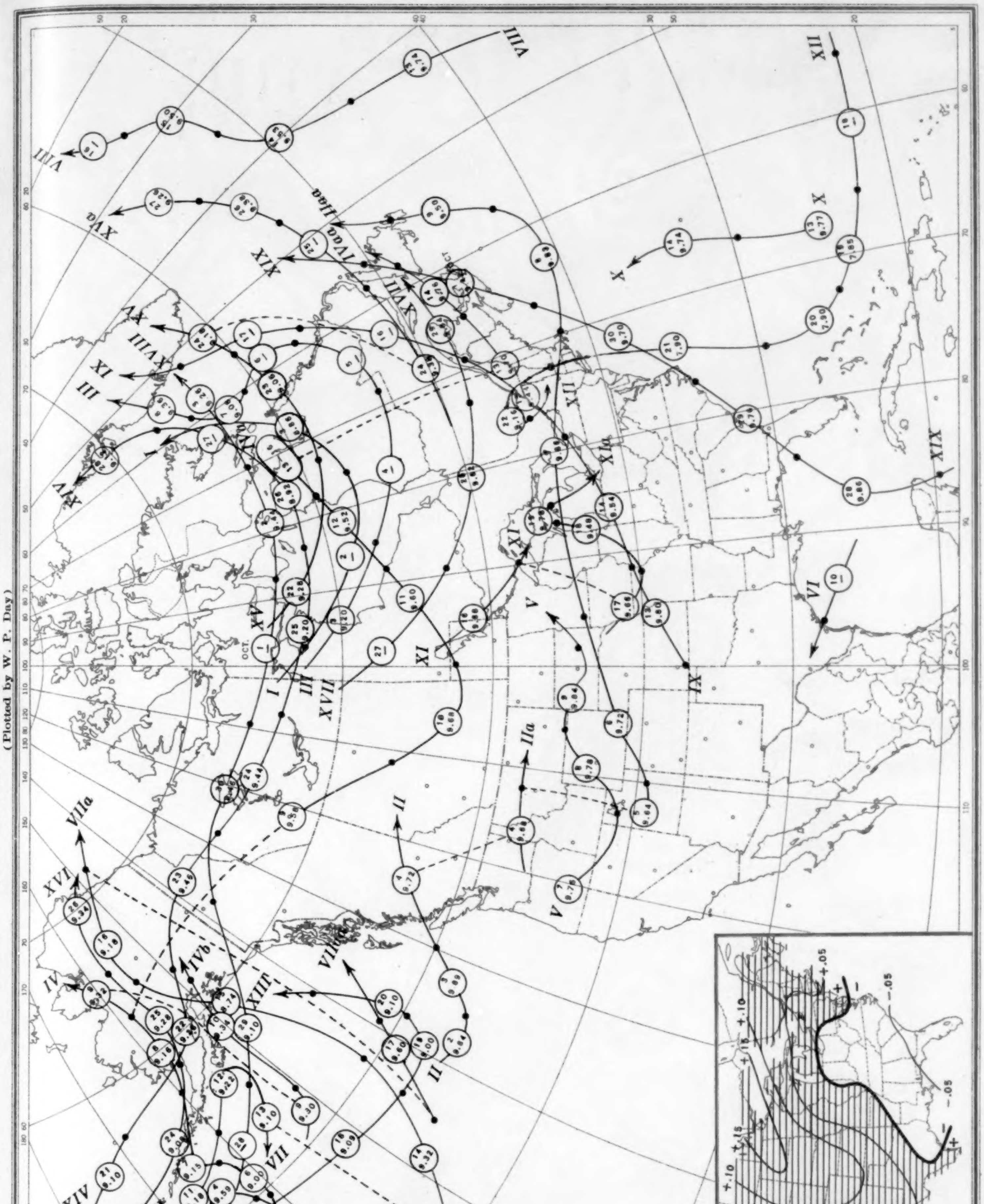


Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 7:30 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, Setpember 1938. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by W. P. Day)

Chart III. Tracks of Centers of Cyclones, Setpember 1938. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by W. P. Day)



Circle indicates position of cyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 7:30 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, September 1938

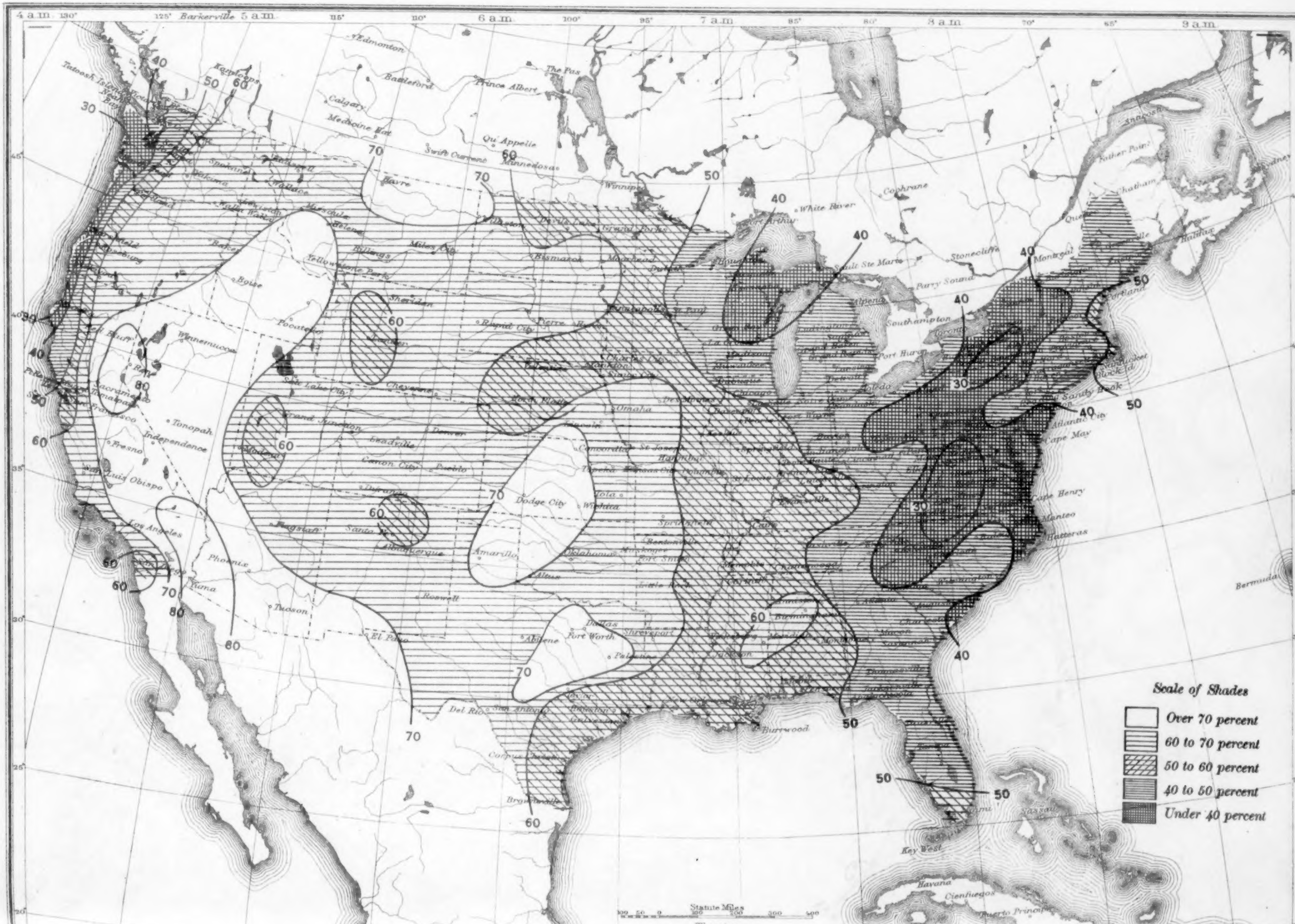


Chart V. Total Precipitation, Inches, September 1938. (Inset) Departure of Precipitation from Normal

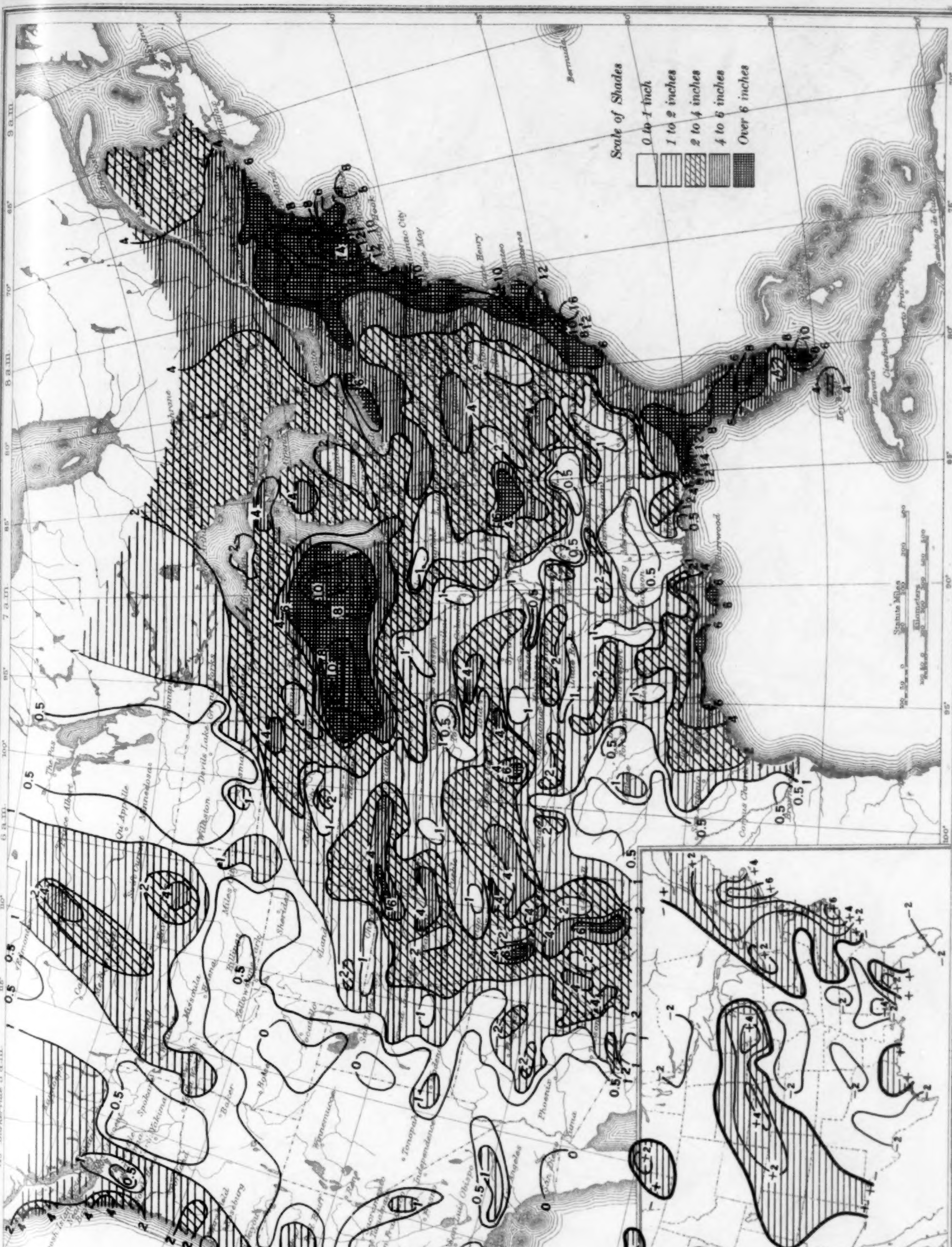


Chart V. Total Precipitation, Inches, September 1938. (Inset) Departure of Precipitation from Normal

Chart VI. Isobars at Sea Level and Isotherms at Surface; Prevailing Winds, September 1938

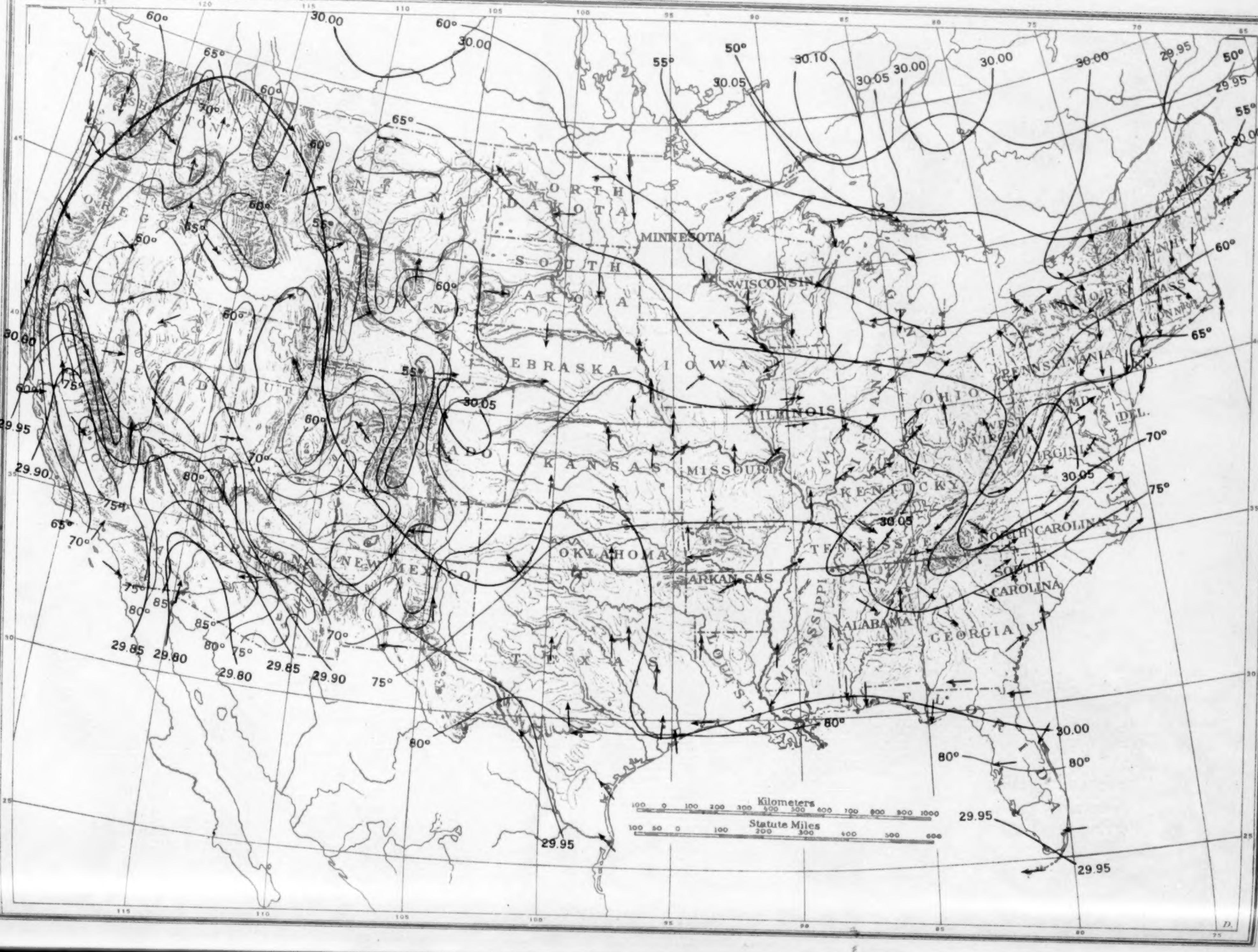


Chart VII. Wind Roses for Selected Stations, September 1938
(Plotted by J. P. Kohler)

Chart VII. Wind Roses for Selected Stations, September 1938
(Plotted by J. P. Kohler)

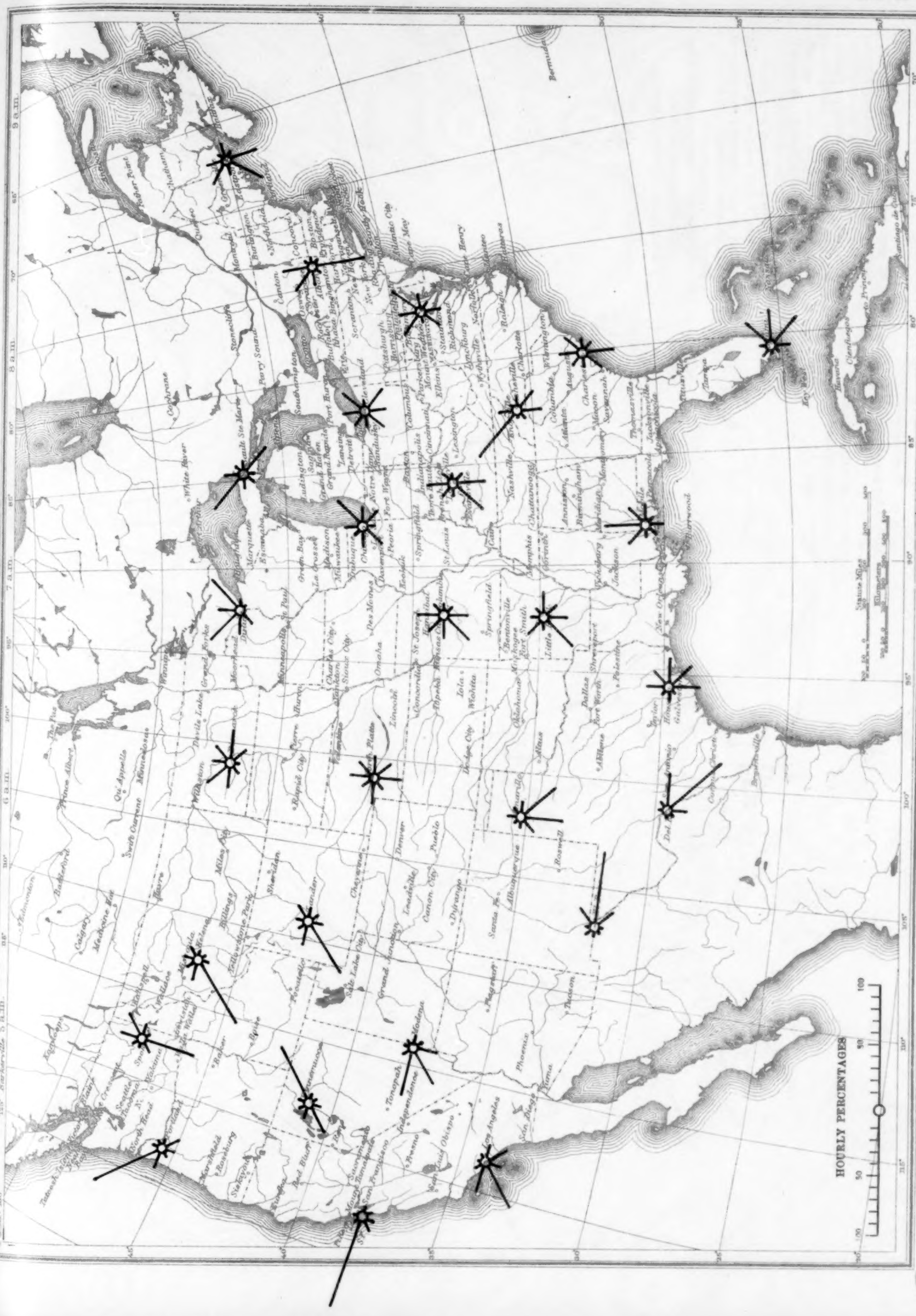


Chart IX. Weather Map of North Atlantic Ocean, September 20, 1938, and Track of the Hurricane of September 18-22, 1938
(Plotted from the Weather Bureau Northern Hemisphere Chart)

Chart IX. Weather Map of North Atlantic Ocean, September 20, 1938, and Track of the Hurricane of September 16-22, 1938

(Plotted from the Weather Bureau Northern Hemisphere Chart)

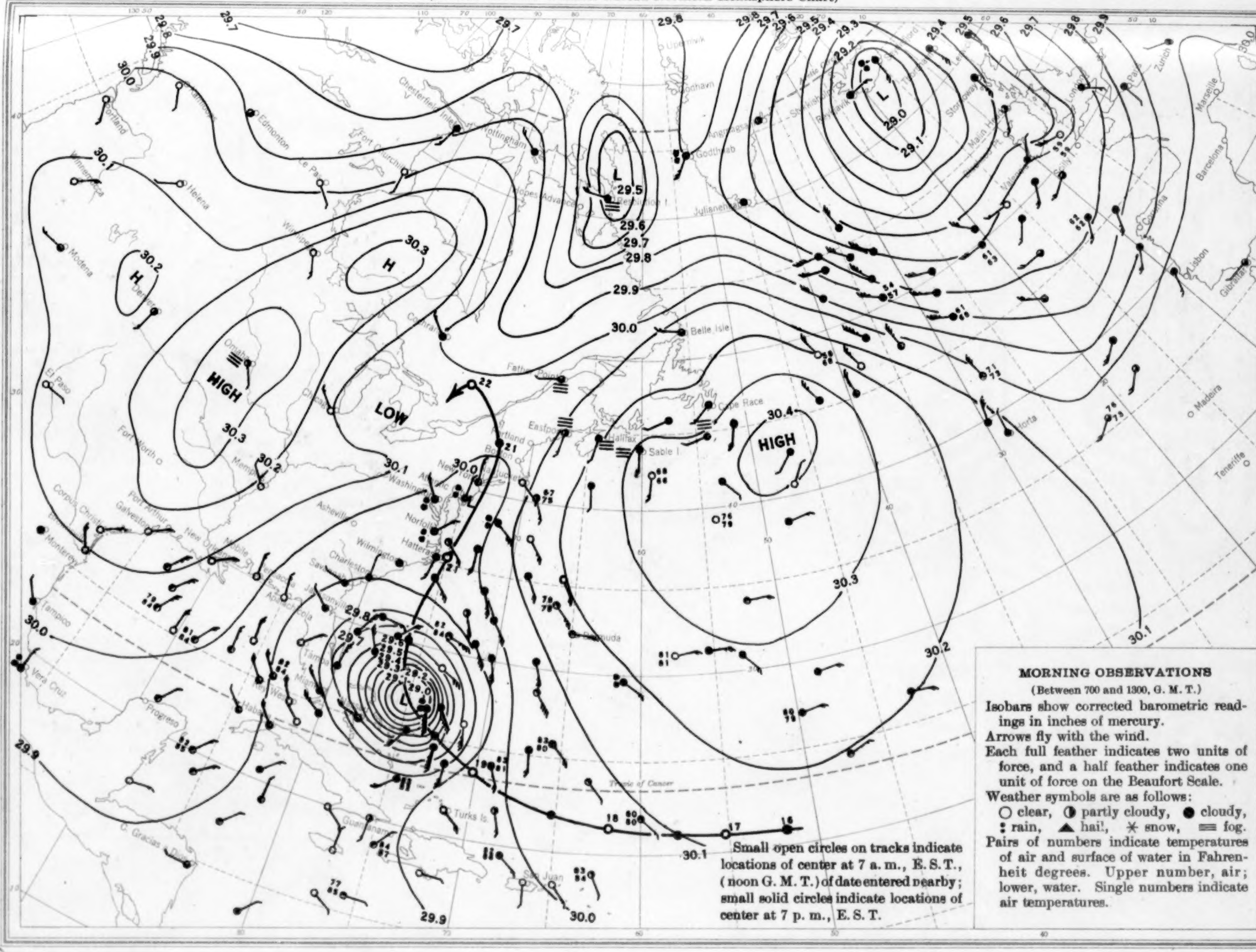


Chart X. Tracks of Centers of Hurricanes of 1815 and 1821

Chart X. Tracks of Centers of Hurricanes of 1815 and 1821